Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations   1. Thesis and Dissertation Collection, all items

1999-03

Evaluation and methods to reduce co-channel interference on the reverse channel of a CDMA cellular system

Durak, Adem.

Monterey, California: Naval Postgraduate School

http://hdl.handle.net/10945/13600

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

EVALUATION AND METHODS TO REDUCE CO-CHANNEL INTERFERENCE ON THE REVERSE CHANNEL OF A CDMA CELLULAR SYSTEM

by

Adem Durak

March 1999

Thesis Advisor: Tri T. Ha
Co-Advisor: Ralph D. Hippenstiel

Approved for public release; distribution is unlimited.

19990325 054

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 1999	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE Evaluation and Methods to Reduce Co-Channel Interference on the Reverse Channel of a CDMA Cellular System.	5. FUNDING NUMBERS
6. AUTHOR(S) Durak, Adem	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

With increasing exploitation of information, the demand for mobile access to high data rate multimedia services including high speed internet connection, high quality video/images, teleconferencing, and file transfer continues to grow rapidly for a wide variety of military as well as commercial applications.

The current mobile communication systems are narrowband and optimized for voice. They can not support high data rate applications. Simply increasing the bandwidth of existing systems will result in severe degradation due to frequency selective fading, resulting in loss of quality and reliability. It appears that CDMA is the strongest candidate for the third generation mobile communication systems to support these demands. CDMA minimizes the effects of frequency selective fading while reducing the probability of detection and interception by non-authorized users.

The primary restriction of the performance of CDMA is the co-channel interference. Since CDMA capacity is only interference limited, the interference reduction equates to better quality of service and greater user capacity. This thesis focuses on analyzing the co-channel interference on the reverse channel of the proposed CDMA cellular systems operating with perfect power control and investigating methods such as sectoring and microzoning in an effort to reduce the interference.

14. SUBJECT TERMS Cellular Communications, Spread Spectrum, CDMA, Co-Channel Interference, Reverse Channel, Interference Reduction.	15. NUMBER OF PAGES 102
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

EVALUATION AND METHODS TO REDUCE CO-CHANNEL INTERFERENCE ON THE REVERSE CHANNEL OF A CDMA CELLULAR SYSTEM

Adem Durak
Lieutenant Junior Grade, Turkish Navy
B.S., Turkish Naval Academy, 1993

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1999

Author: _____
Adem Durak

Approved by: _____
Tri T. Ha, Thesis Advisor

_____
Ralph D. Hippenstiel, Co-Advisor

_____
Jeffrey Knorr, Chairman
Department of Electrical and Computer Engineering

ABSTRACT

With increasing exploitation of information, the demand for mobile access to high data rate multimedia services including high speed internet connection, high quality video/images, teleconferencing, and file transfer continues to grow rapidly for a wide variety of military as well as commercial applications.

The current mobile communication systems are narrowband and optimized for voice. They can not support high data rate applications. Simply increasing the bandwidth of existing systems will result in severe degradation due to frequency selective fading, resulting in loss of quality and reliability. It appears that CDMA is the strongest candidate for the third generation mobile communication systems to support these demands. CDMA minimizes the effects of frequency selective fading while reducing the probability of detection and interception by non-authorized users.

The primary restriction of the performance of CDMA is the co-channel interference. Since CDMA capacity is only interference limited, the interference reduction equates to better quality of service and greater user capacity. This thesis focuses on analyzing the co-channel interference on the reverse channel of the proposed CDMA cellular systems operating with perfect power control and investigating methods such as sectoring and microzoning in an effort to reduce the interference.

TABLE OF CONTENTS

I.   INTRODUCTION

The demand for mobile access to high data rate multimedia services including high speed internet connection, high quality video/images, teleconferencing, and file transfer is increasing. The current mobile communication systems are narrowband and optimized for voice. They can not support high data rate applications. Increasing the bandwidth of existing systems will result in degradation due to frequency selective fading, resulting in loss of quality and reliability. Code Division Multiple Access (CDMA) is a strong candidate for the third generation mobile communication systems to support these demands. CDMA minimizes the effects of frequency selective fading while reducing the probability of detection and interception by non-authorized users.

The primary restriction of the performance of CDMA is the co-channel interference. Interference reduction equates to better quality of service and greater user capacity. This thesis focuses on analyzing the co-channel interference on the reverse channel of the proposed CDMA cellular systems operating with perfect power control. It also investigates sectoring and microzoning methods in an effort to reduce the interference.

A. THESIS OUTLINE

Chapter I presents the evolution, concept, capacity, and advantages of the CDMA technology, and explains the reason why to go to high data rate cellular systems. Chapter II presents the generalized signal to interference ratio, cell structure, and propagation model which will be used. It also derives the Signal to interference ratio (SIR) for the CDMA systems employing omni-directional antennas. Chapter III presents the reverse channel analysis and SIR for the sectoring, perfect and imperfect sectoring cases, and the

soft/softer handoff technique, which is one of the most important advantages of CDMA cellular systems. Chapter IV applies the microzoning concept, originally devised for narrowband systems, to the CDMA system and presents the analysis and SIR of the CDMA system using the microzoning concept. Chapter V presents simulations which compare three different CDMA configurations employing omni-directional antenna, sectoring, and microzoning.

B. THESIS CONTRIBUTION

The primary restriction of the performance of CDMA is the co-channel interference. Since the CDMA capacity is only interference limited, the interference reduction equates to better quality of service and greater user capacity in CDMA. This thesis focuses on analyzing the co-channel interference on the reverse channel of the proposed CDMA cellular systems operating with perfect power control and investigates methods such as sectoring and microzoning in an effort to reduce the interference. The analysis and simulations show that microzoning coupled with 60^0 sectoring provide the necessary interference reduction to enable the operation of the third generation high data rate cellular systems.

C. EVOLUTION OF CODE DIVISION MULTIPLE ACCESS

Spread spectrum (SS) communication technology is the basis of CDMA system and has been used in military communications (specially by the US Military) for many years. In this area, spread spectrum techniques were generally used to overcome the effects of strong intentional interference by hostile jamming, and to hide the desired signal from the eavesdropper. Both goals can be achieved by spreading the signal's

spectrum by reducing the spectral density of the signal. This tends to make the signal virtually indistinguishable from the channel noise.

The application of the CDMA system to the commercial mobile communication area was proposed in the 1950's, but its practical application did not take place until 1980's due to the many technical obstacles and the sufficiency of the mobile systems in use at that time.

Increases in demand and the poor quality of the existing service led mobile service providers to research different ways to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular communication use was limited, efficient use of the required frequencies was needed for mobile cellular coverage.

During 1980's Qualcomm investigated Direct Sequence CDMA (DS-CDMA) techniques, and demonstrated that CDMA would work as well in practice as it did in theory. This led to the standardization of CDMA known as IS-95.

D. CDMA CONCEPT

CDMA technology makes use of the "direct sequence" method of spread spectrum. Direct sequence is a spread spectrum technique in which the bandwidth of a signal is increased by artificially increasing the transmission rate. This is done by breaking each bit into a number of sub-bits called "chips".

Each user is assigned a unique sequence that it uses to encode its information-bearing signal. The receiver, knowing the code sequences of the user, decodes a received signal after reception and recovers the original data. This is possible since the crosscorrelations between the code of the intended user and the codes of the other users

3

are small. Since the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal, the encoding process enlarges or spreads the spectrum of the signal and is known as spread spectrum modulation [Ref. 1].

It is the spectral spreading of the transmitted signal that gives CDMA its multiple access capability. It is therefore important to know the techniques to generate spread spectrum signals and the properties of these signals. Spread spectrum modulation technique uses two concepts: (1) the transmission bandwidth is much larger than the information bandwidth, and (2) the resulting radio-frequency bandwidth is determined by a code other than the information being sent (so the bandwidth is independent of the information signal). Therefore, spread spectrum modulation transforms an information-bearing signal into a transmission signal with a much larger bandwidth. This spreads the original signal power over a much broader bandwidth, resulting in a lower power spectral density. The receiver correlates the received signal with a synchronously generated replica of the code signal to recover the original information-bearing signal. This requires that the receiver must know the code signal used to modulate the data [Ref. 1].

E. DEMAND FOR HIGH DATA RATE CELLULAR SYSTEMS

The main purpose of the mobile communication systems is to provide mobile users sufficient communication opportunity anytime and anywhere. With the increasing demand of the information age, we need to add one more important objective to the current mobile communication systems. That is to provide multimedia services including high speed internet connection, high quality video/images, and teleconferencing capabilities to mobile users.

However, the current mobile communication systems, that is second generation systems, are narrowband and optimized for voice. They can not support high data rate applications. Simply increasing the bandwidths of the existing systems will result in severe degradation due to the frequency-selective fading, resulting in loss of quality and reduced reliability [Ref. 2]. Therefore, to support these demands toward the goal of wideband mobile multimedia services, a third generation high data rate mobile communication system which is called IMT-2000 (International Mobile Telecommunications System-2000) is being developed. It appears that CDMA is the strongest candidate for the third generation mobile communication systems. CDMA utilizes site diversity and exploits multipath fading through Rake combining [Ref. 2], while reducing the probability of detection and interception.

F. SPREAD SPECTRUM SIGNAL PROPERTIES

Because of the coding and the resulting enlarged bandwidth, spread spectrum signals have a number of properties that differ from the properties of narrowband signals. The most important properties of spread spectrum signals are discussed below [Ref. 1].

1. Multiple access capability. If multiple users transmit spread spectrum signals at the same time, the receiver will still be able to distinguish between the users, provided each user has a unique code that has a sufficiently low cross-correlation with the other codes. Correlating the received signal with a code signal from a certain user will then only despread the signal of this user, while the other spread spectrum signals will remain spread over a large bandwidth. Thus, within the information bandwidth the power of the desired user will be

5

much larger than the interfering power provided there are not too many interferers, and the desired signal can be extracted.

2. Protection against multipath interference. In a radio channel there is not just one path between a transmitter and receiver. Due to reflections (and refractions) a signal will be received over a number of different paths. The signals of the different paths are all copies of the transmitted signal but with different amplitudes and phases. Adding these signals at the receiver will be constructive at some of the frequencies and destructive at others. In the time domain, this results in a dispersed signal. Spread spectrum modulation can combat this multipath interference. Although multipath is usually detrimental to an analog or Time Division Multiple Access (TDMA) signal, it is actually an advantage to CDMA, since the CDMA "Rake receiver" can use multipath to improve a signal. The CDMA receiver has a number of receive "fingers" which are capable of receiving the various multipath signals. The receiver locks onto the dominant received multipath signals, time shifts them, and then sums them together to produce a signal that is better than any of the individual signal components. Adding the multipath signals together enhances the signal rather than degrading it.

3. Privacy. The transmitted signal can only be despread and the data recovered if the code is known to the receiver.

4. Interference rejection. Cross-correlating the code signal with a narrowband signal will spread the power of the narrowband signal thereby reducing the interfering power in the information bandwidth.

6

5. Anti-jamming capability, especially narrowband jamming. This is more or less the same as interference rejection except the interference is now willfully inflicted on the system. It is the property together with the next one that makes spread spectrum modulation attractive for military applications.

6. Low probability of interception. Because of its lower power density, the spread spectrum signal is difficult to detect.

G. CAPACITY AND ADVANTAGES OF CDMA SYSTEMS

CDMA has a real capacity advantage over other multiple-access techniques in a high-density multicell network. This is a direct consequence of spatial isolation due to high propagation losses in the UHF band, spread spectrum immunity to interference, and monitoring of voice activity. As a result, in a CDMA multiple-cell network it is possible to use the same frequency band in all cells as opposed to narrowband multiple access techniques in which the bandwidth used in a given cell can be reused only in a sufficiently far away cells so that the interference is not significant. In order to compare CDMA with other multiple access schemes, capacity is measured as the total number of users in a multiple-cell network rather than the number of users per bandwidth or per isolated cell. Based on this criterion, capacity of a CDMA high-density multiple-cell network is much higher than with narrowband multiple access techniques. The key difference is that CDMA allows 100% frequency of reuse among all cells in a network [Ref. 3]. In other words, all users in a CDMA system share the same RF spectrum. This is one of the advantages which gives CDMA its greater capacity over the other multiple access techniques, but it also makes certain aspects of system planning more straightforward. It provides simplified system planning through the use of the same

frequency in every sector of every cell. Thus, engineers will no longer have to perform the detailed frequency planning which is necessary in other systems.

Another important point is that the capacity of CDMA systems is interference limited. Thus, the key issue in CDMA network design is minimization of multiple access interference. Power control is critical to multiple access interference. Each base station controls the transmit power of its own users.

Another important consideration in increasing the system capacity is voice activity monitoring. In a two-person conversation, each speaker is active only 35% to 40% of the time and listens to the rest of the time. In CDMA, all the users share one radio channel. When users assigned to the channel do not talk, all other active users experience lower interference. Thus, the voice activity monitoring reduces multiple access interference by 65%. This translates into an increase of the system capacity by a factor of 2.5 [Ref. 3]. CDMA system also uses variable rate vocoders. The variable rate vocoder will increase its rate, providing the best speech quality, only when voice activity is detected. Otherwise, when no voice activity is detected, the vocoder will drop its encoding rate, because there is no reason to have high speed encoding of silence. Therefore, the variable rate vocoder uses up channel capacity only as needed.

In narrowband systems, additional capacity is needed to maintain low co-channel interference. In Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) guard times and guard bands take up to 20% of the overall capacity. CDMA networks are designed to tolerate a certain level of interference and thus have a capacity advantage in this respect compared to narrowband techniques [Ref. 3].

Another important point is reduction of E_b/N_0 and Interference Threshold. In the other systems the desired signal must be at least 17dB (9 dB in Global System for Mobile-GSM) above any noise or interference [Ref. 4]. The effect of this is that adjacent cells can not share the same portion of the spectrum. The problem with this is that not all of the channels in adjacent cells can be used. In CDMA, signals can be received in very high levels of interference. Under worst case conditions, a signal can be received in the presence of interference that is 18dB higher than the signal [Ref. 4]. Because of this, channels can be reused in adjacent cells. Typically half of the interference in a cell is due to adjacent cells. The ability of a CDMA system to receive a signal under such high noise interference conditions is a result of the digital coding process used in spreading the signal. The coding gain of the signal is the ratio of the transmitted bits to the data bits. The North American standard coding gain is 128 or 21dB. Since only 3dB of signal power is required for signal reception, this means that 18dB of noise can be tolerated [Ref. 4]. The signal can be resolved because there is minimal cross-correlation between all of the signals on the channel. This is a characteristic of the orthogonality and uniqueness of the spreading codes.

H. CO-CHANNEL INTERFERENCE AND INTERFERENCE REDUCTION METHODS TO INCREASE THE CDMA CAPACITY

The signal to interference ratio (SIR) determines the quality of service experienced by the base station in reverse channel (mobile to base station) and by the mobile user in the forward channel (base station to mobile) in a CDMA system. Co-channel interference is a limiting factor in a cellular mobile radio system. Therefore,

computing the signal to interference ratio is important for determining coverage, capacity, and quality of service in a CDMA system.

This thesis will examine the signal to noise ratio (S/N) due to the additive white Gaussian noise (AWGN), intracell interference, and co-channel interference in the reverse channel of CDMA for several different types of cellular architectures. Several methods will be introduced and examined in an effort to reduce co-channel interference in the reverse channel.

The reverse channel presents the most difficulty in CDMA cellular systems for several reasons. First of all, the base station has complete control over the relative power of all of the transmitted signals on the forward link; however, because of different radio propagation paths between each user and the base station, the transmitted power from each portable unit must be dynamically controlled to prevent any single user from driving the interference level too high for all other users [Ref. 5]. Second, transmit power is limited by battery consumption at the portable unit, therefore there are limits on the degree to which power may be controlled. Finally, to maximize performance, all users on the forward link may be synchronized much more easily than users on the reverse link [Ref. 6,7].

II.   REVERSE CHANNEL ANALYSIS OF CDMA CELLULAR SYSTEMS EMPLOYING OMNI-DIRECTIONAL ANTENNAS

Consistent with current CDMA designs, we assume that there are separate frequency bands for the reverse link (mobile to base) and the forward link (base to mobile). In this chapter, we also assume that all transmitters, whether in bases or in mobiles, employ omni-directional antennas.

These two assumptions imply that any mobile in the system experiences interference from all base stations, but does not experience interference from other mobiles (forward link). Similarly, a given base station experiences interference from all mobiles in the system, but not from other base stations (reverse link). In this thesis, we deal with the reverse link only. The forward link analysis was addressed in [Ref. 8].

Although all co-channel cells interfere with each other, we will analyze only the first and second tiers since the interference from subsequent tiers is negligible when compared to the first and second tiers.

Using a hexagonal cell layout, the reference cell 0 and the adjacent first (labeled by a single letter) and second tier (labeled by double letters) cells are shown in Figure 2.1.
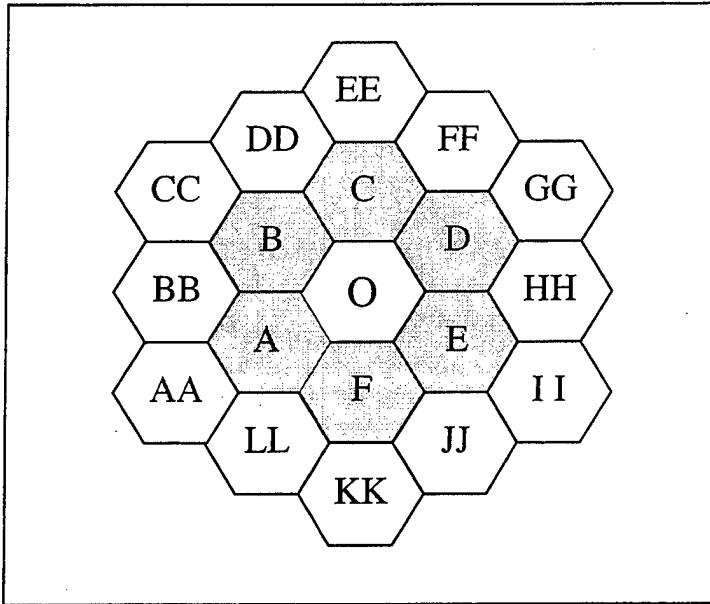
Figure 2.1: Reference cell with the first (gray shaded) and second tier co-channel cells.

To derive an expression for the signal to interference ratio due to co-channel interference, we have to consider several factors: additive white Gaussian noise (AWGN), the spreading factor, the number of users in the reference cell 0, the number of users in each of the co-channel cells, the path loss exponents for each of the cells, and the ratio of the power of the interfering co-channel users to the desired user's power as received by the reference base station.

A. THE GENERALIZED SIGNAL TO INTERFERENCE RATIO

Using the approximations in [Ref. 9], we can obtain the generalized expression for the signal to interference ratio (SIR) of the reverse link of the CDMA system as follows:

$$
\frac{S}{I} = \left[\left(\frac{E_b}{N_0} \right)^{-1} + \left(\frac{S}{I} \right)_{in-cell}^{-1} + \left(\frac{S}{I} \right)_{tier-1}^{-1} + \left(\frac{S}{I} \right)_{tier-2}^{-1} \right]^{-1}, \qquad (2.1)
$$

where E_b/N_0 is the signal energy per bit-to-noise ratio, N_0 is the one-sided noise power spectral density, $E_b = P_oT_b$ is the average bit energy, T_b is the bit duration, and P_o is the signal power of the desired user.

The second term in (2.1) is the intracell interference caused by the other users in the reference cell given as $\left(\dfrac{S}{I}\right)_{in-cell}$, and is given by [Ref. 10];

$$\left(\frac{S}{I}\right)_{in-cell} = \frac{E_k}{\gamma \sum_{\substack{i=1 \\ i \neq k}}^{K} E_i} \, , \tag{2.2}$$

where γ is the normalized variance of the multiuser interference (MUI) within the reference cell, E_k is the bit energy of the desired mobile, E_i is the bit energy of the undesired mobiles within the reference cell, and K is the number of users in the cell.

For the pseudo-random spreading codes with the rectangular chip pulse shape, γ is given by [Ref. 10] as

$$\gamma = \left(1 - \Delta_m + \frac{2}{3}\Delta_m^2\right)/N \, , \tag{2.3}$$

where the normalized offset, $\Delta_i = \tau_i / T_c$ for the ith user is uniformly distributed within $\left[-\Delta_m, \Delta_m\right]$ and $0 \leq \Delta_m < 1$, τ_i is the delay of the ith user's signal, T_c is the chip period, and N is the spreading factor.

Assuming an asynchronous reception, that is $\Delta_m = 1$, in the reverse link, we can rewrite (2.3) as

13

$$\gamma = \frac{2}{3N} \ . \tag{2.4}$$

We also assume that power control (each mobile transmitter power level is controlled by its base station) is employed within the each cell, and all mobiles have equal signal power at the base station within the cell, i.e., $E_i = E_k = E_b$.

Assuming a channel activity factor α (such as voice activity) and substituting (2.4) into (2.2), we obtain

$$\left(\frac{S}{I} \right)_{in-cell} = \frac{E_b}{\frac{2\alpha}{3N} \sum\limits_{\substack{i=1 \\ i \neq k}}^{K} E_b} = \frac{3N}{2(K-1)\alpha} \ , \tag{2.5}$$

and the second term of (2.1) as

$$\left(\frac{S}{I} \right)_{in-cell}^{-1} = \frac{2(K-1)\alpha}{3N} \ , \tag{2.6}$$

where K is the number of users in the reference cell.

The third term in (2.1) is the first tier co-channel interference at the base station of interest and is given as

$$\left(\frac{S}{I} \right)_{tier-1}^{-1} = \sum\limits_{i=1}^{i_0} \frac{2\alpha}{3N} \left(\sum\limits_{k=1}^{K_i} \frac{P_{ik}}{P_o} \right), \tag{2.7}$$

where P_0 is the average received signal power at the reference base station, i_0 is the number of the first tier co-channel cells, K_i is the number of users within the ith co-channel cell, P_{ik} is the average received power at the reference base station due to the kth user in the ith co-channel cell, and α is the channel activity factor.

The last term in (2.1) is the second-tier co-channel interference at the base station of interest and is given as

$$\left(\frac{S}{I}\right)_{tier-2}^{-1} = \sum_{j=1}^{j_0} \frac{2\alpha}{3N}\left(\sum_{k=1}^{K_j} \frac{P_{jk}}{P_o}\right), \qquad (2.8)$$

where P_0 is the average received signal power at the reference base station, j_0 is the number of second tier co-channel cells, K_j is the number of users within the jth co-channel cell, P_{jk} is the average received signal power at the reference base station due to the kth user in the jth co-channel cell, and α is the channel activity factor.

B. THE CELL STRUCTURE AND LOCATION OF THE MOBILE STATIONS

In this thesis, we consider a standard, two-dimensional hexagonal cell layout with base stations in the center of every cell. A mobile station (MS) connects to the closest base station (BS) and is power controlled by that base station. We also assume that each cell consists of 7 "small hexagons" and each active user is at the center of one of these small hexagons, as shown in Figure 2.2.
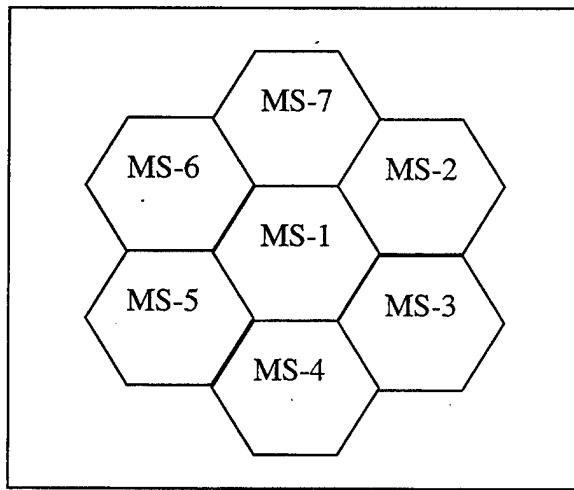

Figure 2.2: 7 active users in a cell with each mobile at the center of a "small hexagon".

15

C. THE DISTANCE CALCULATIONS OF THE MOBILE STATIONS OF OTHER CELLS TO THE REFERENCE BASE STATION

To simplify the calculation of the distances between the reference base station and the interfering mobile stations in the co-channel cells, we locate the reference base station at the center of a x-y coordinate system, that is the coordinates of the reference base station is (0,0). We can then easily obtain the coordinates of the interfering mobile stations as shown in Figure 2.3.
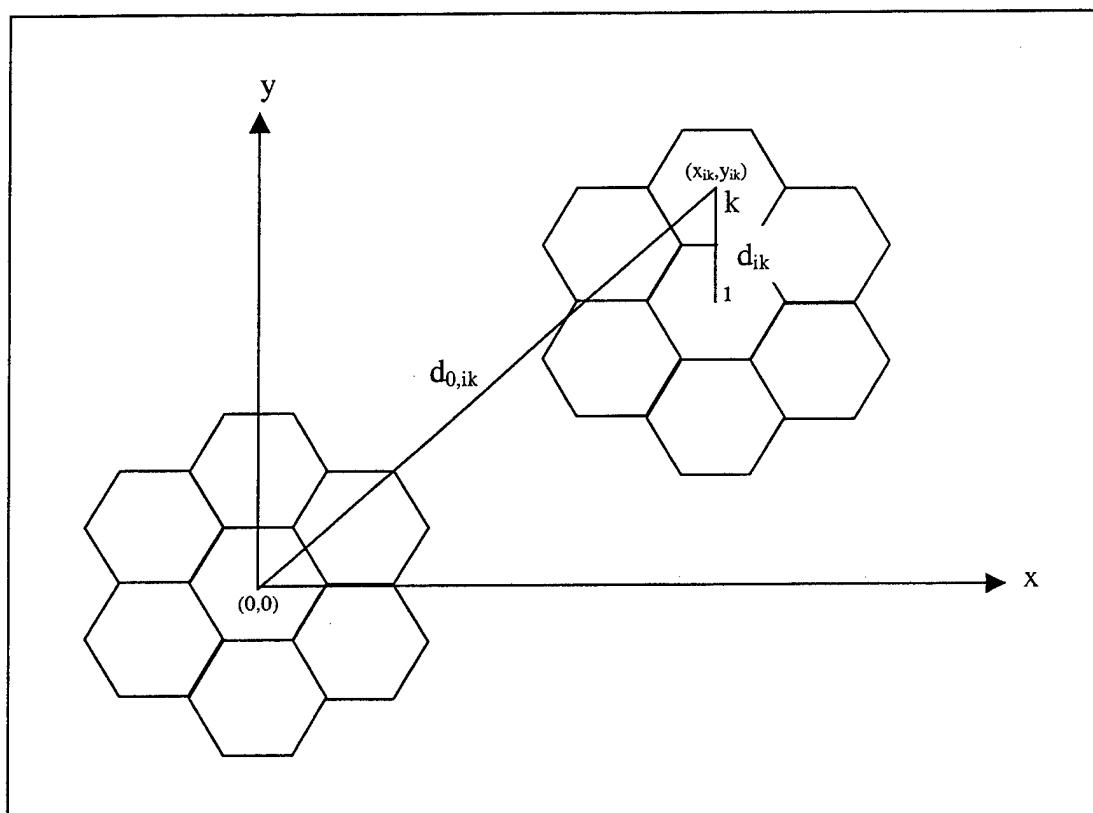

Figure 2.3: The coordinates of the reference base station and an interfering mobile station.

The distance between an interfering mobile station and the reference base station is

$$d_{0,ik} = \sqrt{x_{ik}^2 + y_{ik}^2} \qquad (2.9)$$

where (x_{ik}, y_{ik}) is the coordinate of the kth mobile station in the ith co-channel cell, relative to the reference base station.

The location of each mobile station in the first and second tier co-channel cells is determined and its distance to the reference base station calculated (see Appendix).

We also have to know the distance between the interfering mobile station and its base station to derive transmitted signal power of the interfering mobile station. From Figure 3 we obtain the distance between each mobile station and its own base station as

$$d_{ik} = \sqrt{3}R, \quad i \neq 1, \qquad (2.10)$$

where the cell radius R is the distance from the center of the cell to any of the six vertices of the small hexagons.

We have to make another assumption for the distance of the interfering mobile station in the center of the first "small hexagonal cell". Otherwise, the center mobile station of each co-channel cell and its base station will be at the same location, that is, the required signal power of the first mobile station will be approximately 0 due to the 0 distance. To manage this phenomena, we assume that the center mobile station in each co-channel cell is located R/2 units from its base station, that is $d_{i1}=R/2$, in the direction of reference base station for the analysis.

D. PROPAGATION MODEL

Propagation measurements in a mobile radio channel showed that the average received signal strength at any point decays as a power of the distance of separation between a transmitter and receiver [Ref. 9]. Therefore, it is possible to predict the signal to interference ratio (SIR) by using path loss models to estimate the received signal level as a function of distance.

If the transmitter and receiver are separated by d meters, then the received power is given by [Ref. 11]

$$P_r(d) = \beta P_t d^{-n} \qquad (2.11)$$

where P_t is the transmit power, β is a function of carrier frequency, antenna heights, and antenna gains, and assumed to be constant for all paths between an interfering mobile station and the reference base station, n is the path loss exponent which indicates the rate at which the received power, $P_r(d)$, decreases as the distance increases. The value of n depends on the specific propagation environment, and typically ranges between 2 and 4 in urban cellular systems.

It is also possible to obtain the received power expression by using the reference power P_0 and the reference distance (d_0). The average distance power, $P_r(d)$, at a distance d from the transmitting antenna is given by [Ref. 9]

$$P_r(d) = P_0 \left(\frac{d}{d_0} \right)^{-n} \qquad (2.12)$$

where P_0 is the power received at a close-in reference point in the far field region of the antenna at a small distance d_0 from the transmitting antenna.

Assuming perfect power control at the base stations, that is, all base stations receive equal power from their own mobile stations, (i.e., $P_{r,ik}=P_0$) and by using (2.11) and (2.12) with the assumptions above, we obtain the received power P_0 at the base station per mobile in any co-channel cell as

$$P_0 = \beta P_{t,ik} d_{ik}^{-n} , \tag{2.13}$$

where $P_{t,ik}$ is the transmitted signal power of the kth mobile in the ith co-channel cell, d_{ik} is the distance between the kth mobile station and i^{th} base station, and n is the path loss exponent. From (2.13), we get

$$P_{t,ik} = \frac{1}{\beta} P_0 d_{ik}^n . \tag{2.14}$$

Using the same approach, the received signal power P_{ik} at the reference base station by k^{th} mobile station in the ith co-channel cell is given by

$$P_{ik} = \beta P_{t,ik} d_{0,ik}^{-n} , \tag{2.15}$$

where $d_{0,ik}$ is the distance between the kth mobile station in the ith co-channel cell and the reference base station. Substituting (2.14) into (2.15), we get

$$P_{ik} = P_0 d_{ik}^n d_{0,ik}^{-n} , \tag{2.16}$$

or equivalently

$$\frac{P_{ik}}{P_0} = \left(\frac{d_{0,ik}}{d_{ik}} \right)^{-n} . \tag{2.17}$$

We do not account for lognormal shadowing in this thesis. Referring to [Ref. 11], the propagation model obtained above is accurate for distances from 1-20 km with base station antenna heights greater than 30m and in areas with little terrain profile variation. Thus, the model is reasonable for conventional cellular systems in flat service areas but may not be accurate in city microcells which employ small cells and low antennas.

E. SIGNAL TO INTERFERENCE RATIO (SIR) EXPRESSION IN TERMS OF DISTANCES

The illustration of the reference cell with the first and second tier co-channel cells, in a seven-user per cell layout, employing omnidirectional antennas is shown in Figure 2.4.
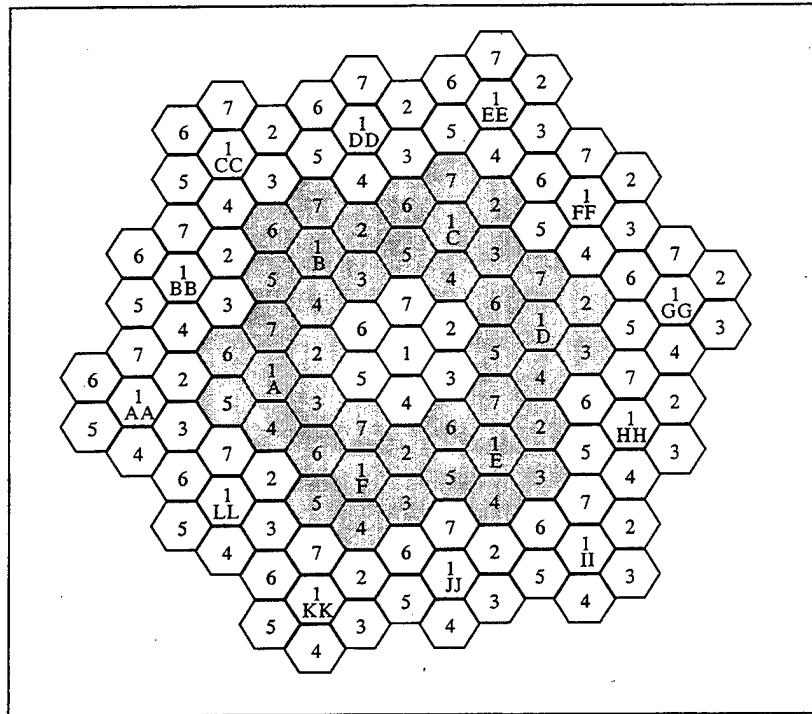

Figure 2.4: The first and second tier co-channel cells using a seven-user per cell layout.

The reference cell is the center cell. The immediate surrounding cells, shaded in gray, are the first tier interfering cells denoted by labels A through F. The second tier co-channel cells are denoted by labels AA through LL. The numbers in the cells show the ith mobile station in each "small hexagons".

We notice that each of the first tier co-channel "small hexagons" has the same distances from the reference base station, for example, $d_{A1} = d_{B1}$, $d_{A2} = d_{B3}$, $d_{A3} = d_{B4}$, $d_{A4} = d_{B5}$, $d_{A5} = d_{B6}$, $d_{A6} = d_{B7}$, $d_{A7} = d_{B2}$, etc.

Assuming the center mobile station in each co-channel cell is located R/2 units from its base station in the direction of the reference base station, and substituting (2.17) into (2.7), the inverse of the SIR for the first tier co-channel cells leads to

$$\left(\frac{S}{I}\right)^{-1}_{tier-1} = \frac{2\alpha}{3N} 6 \left[K_{A_1} \left(\frac{d_{A_1}}{R/2} \right)^{-n} + \sum_{i=2}^{7} K_{A_i} \left(\frac{d_{A_i}}{\sqrt{3}R} \right)^{-n} \right] . \tag{2.18}$$

Using the normalized distance $D_{A_i} = d_{A_i}/R$, we get

$$\left(\frac{S}{I}\right)^{-1}_{tier-1} = \frac{4\alpha}{N} \left[K_{A_1} \left(2D_{A_i} \right)^{-n} + \sum_{i=2}^{7} K_{A_i} \left(\frac{D_{A_i}}{\sqrt{3}} \right)^{-n} \right] , \tag{2.19}$$

where K_{A_1} through K_{A_7} are the number of users in each of the first tier co-channel "small hexagons".

21

Referring to the second-tier co-channel cells, we also notice that the distances of the corresponding mobile stations in each "small hexagon" of the cells AA, CC, EE, GG, II, KK, and also the distances of the corresponding mobile stations in each "small hexagon" of the cells BB, DD, FF, HH, JJ, and LL are the same.

Therefore, substituting (2.17) into (2.8), the inverse of the SIR for the second tier co-channel cells leads to

$$\left(\frac{S}{I}\right)^{-1}_{tier-2} = \frac{2\alpha}{3N} 6\left[K_{AA_1}\left(\frac{d_{AA_1}}{R/2}\right)^{-n} + \sum_{i=2}^{7} K_{AA_i}\left(\frac{d_{AA_i}}{\sqrt{3}R}\right)^{-n} + K_{BB_1}\left(\frac{d_{BB_1}}{R/2}\right)^{-n} + \sum_{i=2}^{7} K_{BB_i}\left(\frac{d_{BB_i}}{\sqrt{3}R}\right)^{-n} \right],$$

(2.20)

where K_{AA_1} through K_{AA_7} are the number of mobile stations in each "small hexagon" of the cells AA, CC, EE, GG, II, KK, and K_{BB_1} through K_{BB_7} are the number of mobile stations in each "small hexagon" of the cells BB, DD, FF, HH, JJ, LL.

Using the normalized distance $D_{AA_i} = d_{AA_i}/R$ and $D_{BB_i} = d_{BB_i}/R$, we get

$$\left(\frac{S}{I}\right)^{-1}_{tier-2} = \frac{4\alpha}{N}\left[K_{AA_1}\left(2D_{AA_1}\right)^{-n} + \sum_{i=2}^{7} K_{AA_i}\left(\frac{D_{AA_i}}{\sqrt{3}}\right)^{-n} + K_{BB_1}\left(2D_{BB_1}\right)^{-n} + \sum_{i=2}^{7} K_{BB_i}\left(\frac{D_{BB_i}}{\sqrt{3}}\right)^{-n} \right]$$

(2.21)

Substituting (2.6), (2.19) and (2.21) into (2.1), we obtain SIR as

$$\left(\frac{S}{I}\right) = \left[\left(\frac{E_b}{N_0}\right)^{-1} + \left(\frac{2(K-1)\alpha}{3N}\right) + \frac{4\alpha}{N}\left(K_{A_1}\left(2D_{A_1}\right)^{-n} + \sum_{i=2}^{7} K_{A_i}\left(\frac{D_{A_i}}{\sqrt{3}}\right)^{-n}\right.\right.$$

$$\left.\left. + K_{AA_1}\left(2D_{AA_1}\right)^{-n} + \sum_{i=2}^{7} K_{AA_i}\left(\frac{D_{AA_i}}{\sqrt{3}}\right)^{-n} + K_{BB_1}\left(2D_{BB_1}\right)^{-n} + \sum_{i=2}^{7} K_{BB_i}\left(\frac{D_{BB_i}}{\sqrt{3}}\right)^{-n}\right)\right]^{-1}.$$

(2.22)

III. REVERSE CHANNEL ANALYSIS IN CDMA CELLULAR SYSTEMS USING SECTORING

One of the most important techniques available to reduce the co-channel interference, and hence, increase the capacity of a CDMA cellular system is sectoring. Sectoring is the replacement of the base station's single omni-directional antenna with several directional antennas. These are used in both for receiving and transmitting from and to a certain sector of the cell as shown in Figure 3.1.
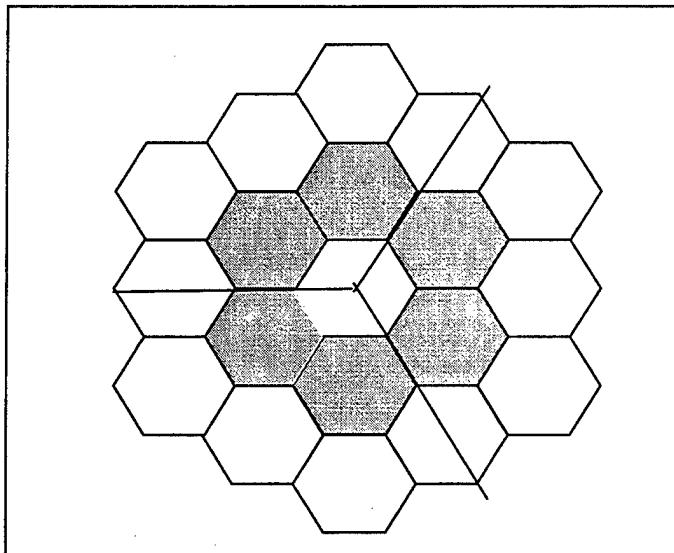

Figure 3.1: 120^0 sectoring with the first (gray shaded) and second tier co-channel cells.

In a traditional narrowband FDMA cellular system, one disadvantage of cell sectoring is that the process of assigning a set of frequencies to each sector decreases the system capacity by the same amount as if that set of frequencies had been designated for distinct cells. Another way to look at it is that the total number of accessible channels in each cell is divided by the number of sectors and assigned to individual antennas. This reduces the available channels per cell by a factor of three for a 120^0 sectoring and a

factor of six for a 60^0 sectoring layout [Ref. 9,12].

However, the CDMA technology does not require a frequency reuse scheme as in the AMPS (Advanced Mobile Phone System), TDMA, or GSM technology. Each cell/sector uses the same carrier frequency and identifies itself via the PN (Pseudo-random) sequence code.

Since CDMA is interference-limited (FDMA and TDMA are primarily bandwidth-limited), any reduction in interference results in an increase in capacity. Thus, any spatial isolation through the use of directional antennas, which reduces interference, also provides a proportional increase in capacity [Ref. 13].

A. PERFECT AND IMPERFECT SECTORING

In the case of perfect directional antennas, as shown in Figure 3.2, there is a sharp separation between the sectors. Thus, the cell is divided into D sectors. Because of perfect sectoring, the number of interfering mobiles decreases with the increase in the number of sectors.
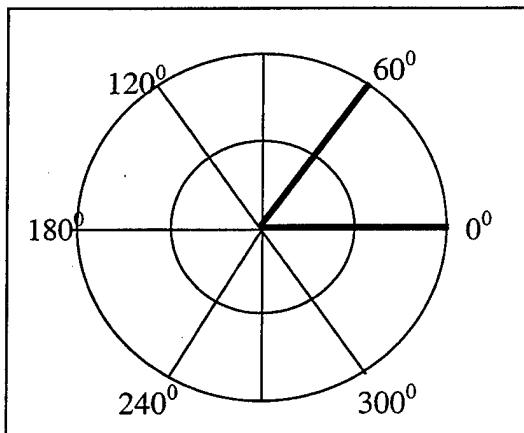

Figure 3.2: Perfect sectoring with 60^0 directional antennas.

For example, with six antennas per base station, each having 60^0 effective beamwidths, the interfering mobiles seen by any antenna are approximately one-sixth of those seen by an omni-directional antenna. This reduces the number of interfering mobile stations by a factor of 6.

However, due to overlap and sidelobes of practical antennas, as shown in Figure 3.3, the base station still receives some interference from users in other sectors. Therefore, perfect sectoring does not exist in practice.
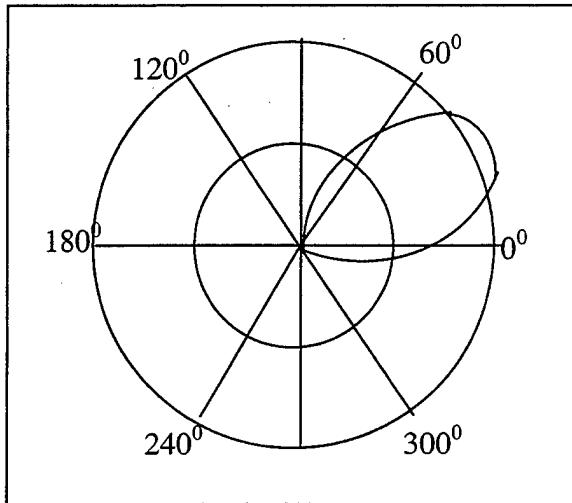

Figure 3.3: Imperfect sectoring with 60^0 directional antenna pattern.

Referring to [Ref. 14], to model the imperfect sectoring, we assume the simplified antenna radiation pattern shown in Figures 3.4(a) and (b) where the antenna imperfections are modeled by the overlap angle v. The overlap angle can be varied and depends on the antenna type. Sectoring into D sectors produces opening angles of $360^0/D$.

(a) (b)
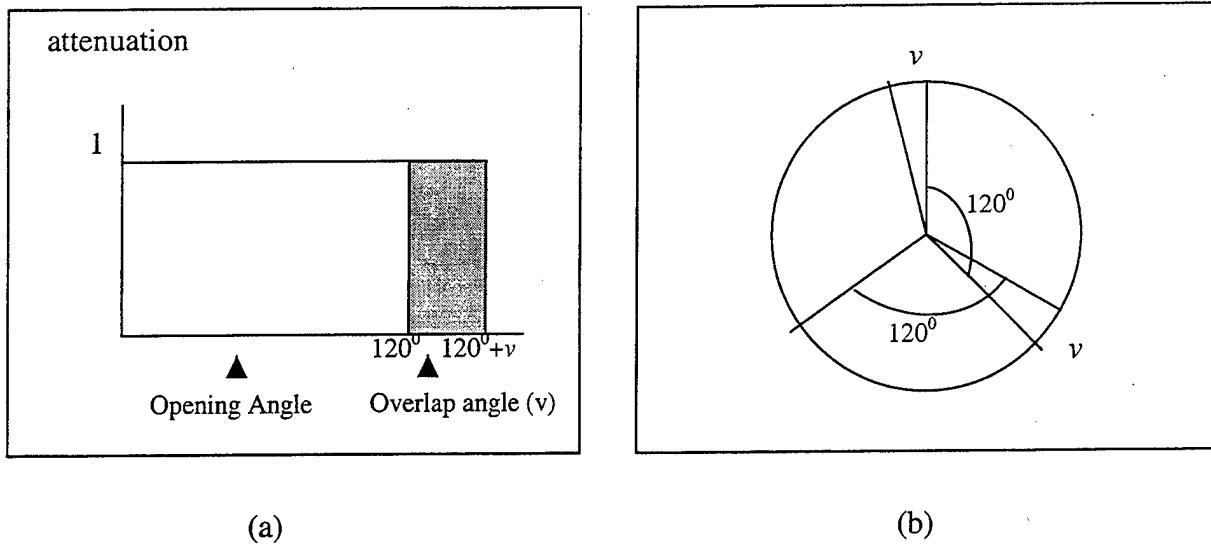
Figure 3.4: (a) Radiation pattern model for imperfect directional antenna with opening angle 120^0. (b) Sector coverage with an imperfect directional antenna with opening angle 120^0.

If D is the number of sectors and v is the overlap angle, then a relation can be derived between the ratio of the total interference power received in a sectorized system and the total interference power received in an omni-directional system denoted by F_s as

$$F_s \cong \frac{P_s}{P} = \left(\frac{1}{D} + \frac{2v}{360} \right) , \tag{3.1}$$

where P_s is the total interference power in a sector, and P is the total interference power in a cell.

As explained in the Chapter II, since we assume that each cell consists of 7 "small hexagons" and each user is at the center of one of these small hexagons, the users are

evenly distributed among the cells. Thus, the number of users in each sector is the total number of users divided by number of sectors. Therefore, the power interference ratio between one sector to the whole cell is the ratio of number of users in that sector to the total number of users in the cell.

Consequently, we can derive F_s in terms of number of total interfering users in a sectorized system and the number of total interfering users in an omni-directional system as

$$F_s \cong \frac{K_s}{K} = \left(\frac{1}{D} + \frac{2v}{360} \right) , \qquad (3.2)$$

where K_s is the total number of interfering users in a sector, and K is the total number of interfering users in an omni-directional antenna system. From (3.1) or (3.2), it is clear that $v=0$ corresponds to perfect sectoring, and the combination $D=1$ and $v=0$ corresponds to the omni-directional antenna system.

B. SIGNAL TO INTERFERENCE RATIO

From the relationship between the sectorized and omni-directional antenna systems in (3.2), we can obtain the SIR for the sectorized system using the SIR of the omni-directional system in (2.1).

Substituting (3.2) into (2.6), we obtain the intra-cell signal to interference ratio for the sectorized antenna system as

$$\left(\frac{S}{I} \right)^{-1}_{S_{in-cell}} = \frac{2 \left(F_s K - 1 \right) \alpha}{3 N} , \qquad (3.3)$$

29

where $K_s = F_s K$.

Using the same approach in the previous chapter, and substituting (2.17) into (2.7), we obtain the third term of (2.1), which is the first tier co-channel interference at the base station of interest for a sector as

$$\left(\frac{S}{I}\right)_{S_{tier-1}}^{-1} = \frac{4\alpha}{N}\left[K_{S_{A_1}}\left(2D_{A_i}\right)^{-n} + \sum_{i=2}^{7} K_{S_{A_i}}\left(\frac{D_{A_i}}{\sqrt{3}}\right)^{-n}\right], \qquad (3.4)$$

and for special case of $F_s K = K_s$ to say $F_s K_A = K_{S_A}$, we can obtain the inverse SIR of the first tier co-channel cells for a sectoring system, in terms of K, as

$$\left(\frac{S}{I}\right)_{S_{tier-1}}^{-1} = \frac{4\alpha F_s}{N}\left[K_{A_1}\left(2D_{A_i}\right)^{-n} + \sum_{i=2}^{7} K_{A_i}\left(\frac{D_{A_i}}{\sqrt{3}}\right)^{-n}\right]. \qquad (3.5)$$

Equivalently, substituting (2.17) into (2.8), and using the same approach above, we obtain the fourth term in (2.1), which is the second tier co-channel interference at the base station of interest, for the sectorized antenna system as

$$\left(\frac{S}{I}\right)_{S_{tier-2}}^{-1} = \frac{4\alpha F_s}{N}\left[K_{AA_1}\left(2D_{AA_1}\right)^{-n} + \sum_{i=2}^{7} K_{AA_i}\left(\frac{D_{AA_i}}{\sqrt{3}}\right)^{-n} + K_{BB_1}\left(2D_{BB_1}\right)^{-n} + \sum_{i=2}^{7} K_{BB_i}\left(\frac{D_{BB_i}}{\sqrt{3}}\right)^{-n}\right].$$

$$(3.6)$$

Substituting (3.3), (3.5) and (3.6) into (2.1), we obtain the SIR of the sectorized antenna system as

$$\left(\frac{S}{I}\right)_s = \left[\left(\frac{E_b}{N_0}\right)^{-1} + \left(\frac{2(F_S K - 1)\alpha}{3N}\right) + \frac{4\alpha F_s}{N}\left(K_{A_1}\left(2D_{A_1}\right)^{-n} + \sum_{i=2}^{7} K_{A_i}\left(\frac{D_{A_i}}{\sqrt{3}}\right)^{-n} \right.\right.$$

$$\left.\left. + K_{AA_1}\left(2D_{AA_1}\right)^{-n} + \sum_{i=2}^{7} K_{AA_i}\left(\frac{D_{AA_i}}{\sqrt{3}}\right)^{-n} + K_{BB_1}\left(2D_{BB_1}\right)^{-n} + \sum_{i=2}^{7} K_{BB_i}\left(\frac{D_{BB_i}}{\sqrt{3}}\right)^{-n} \right) \right]^{-1}.$$

$$(3.7)$$

C. SOFT AND SOFTER HANDOFF

With traditional hard handoffs, which are used in all other types of cellular systems, a mobile station near cell boundaries drops a channel before picking up the next channel. Therefore, there may be a short disruption of speech in narrow band technologies.

On the other hand, with the soft handoff technique, which is used in CDMA cellular systems, a mobile station near cell boundaries is monitored by two ore more base stations simultaneously, as shown in Figure 3.5(a) [Ref. 4]. This figure represents the signal strength versus position of a mobile which is approaching from cell A to cell B. The mobile is monitored by both cell stations due to the similar received signal strength, when it is near to cell boundaries.

Soft handoff is important, because it provides enhanced communication quality

and a smoother transition compared the conventional hard handoff, by providing a "make

before break" connection.
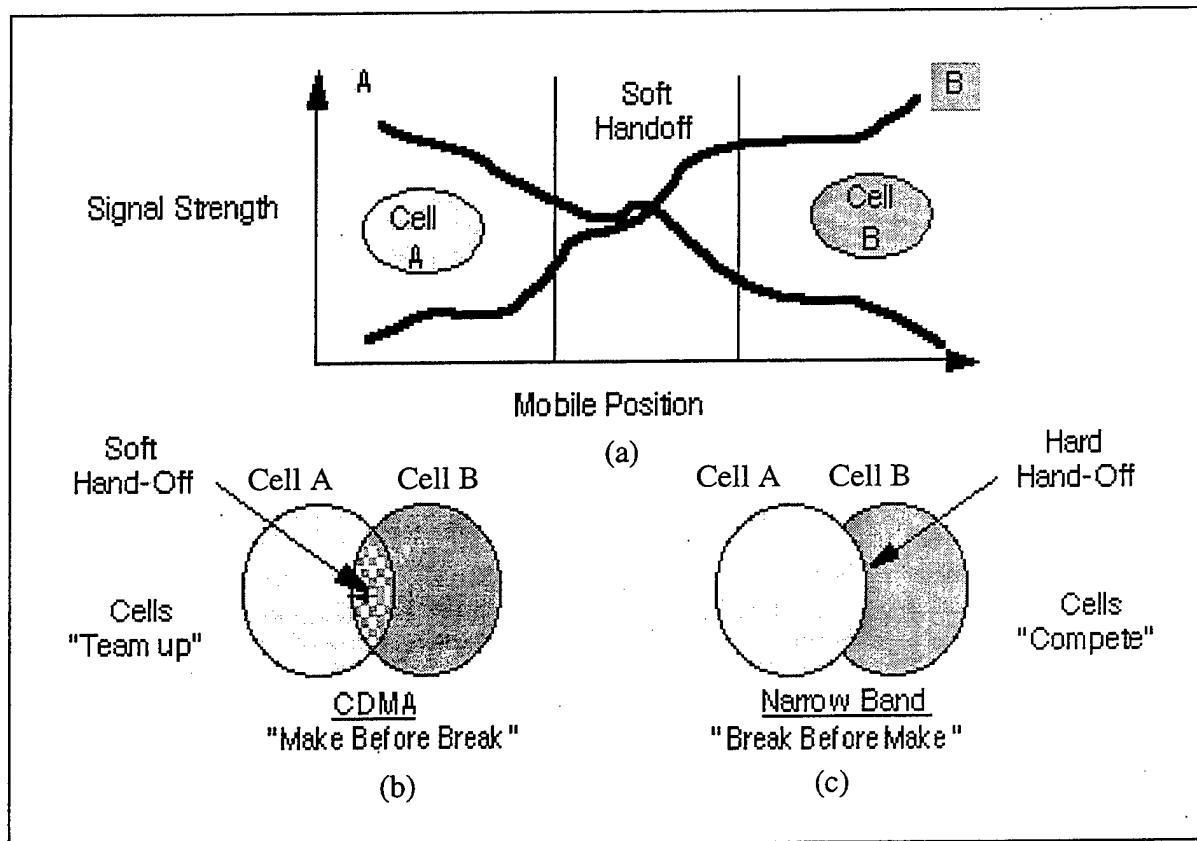
Figure 3.5: (a) Soft handoff pattern for a mobile station in terms of mobile position versus signal strength. (b) "make before break" in CDMA system using soft handoff. (c) "break before make" in Narrow Band cellular systems using hard handoff [Ref. 4].

In CDMA cellular systems, the cells "team up" in the overlapped area (see Figure

3.5(b)) to obtain the best possible combined information stream. Eventually, cell A will

no longer receive a strong enough signal from the mobile, and the mobile will only be

receiving signal from cell B.

On the other hand, narrow band systems "compete" for the signal, and when cell B "wins" over cell A, the user is dropped by cell A (hard handoff) as shown in Figure 3.5(c).

In sectorized CDMA cellular systems, a "softer" handoff occurs when a mobile station is simultaneously communicating with more than one sector within the same cell. In other words, softer handoff is the soft handoff between two sectors of the same cell. Thus, for a sectorized CDMA system, there are two kinds of handoff, namely, handoff between two sectors in different cells (soft handoff), and handoff between two sectors within a cell (softer handoff).

D. OTHER EFFECTS OF SECTORING

There are two important issues we have not considered. First, since the higher sectoring causes more frequent handoff demands, it also demands more system resources. Second, due to the directional antennas, narrower beam antennas provide higher gain, thus, they allow greater distance between the base stations. The change of distance of the base stations and the orientation of antennas will change cell parameters and hence the number of users that can be served [Ref. 15].

IV. THE MICROZONE CONCEPT

As mentioned in Chapter III, the softer handoff is a necessary procedure to support the mobile stations to roam from one sector to another within the same cell, when sectoring is employed. This transition period requires more resources from the network. That is, more handoff (softer handoff in sectoring case) causes an increased load on the switching and control link elements of the mobile systems.

If the distance between base stations is left unchanged, a narrower sector equates to a smaller RF footprint. Thus, if we increase the number of sectors in a cell to increase the capacity, for the mobile stations with the same mobility and call duration, more frequent soft/softer handoff will take place during the call.

Another important consideration is that of homogenous user density. In extreme cases, such as along a seacoast bordered by a mountain range, the user population may be almost linearly distributed along a narrow strip. Obviously, in such cases, sectored antennas are virtually useless because all other-user interference resides in a relatively narrow beamwidth [Ref. 16].

A. DEFINITION OF THE MICROZONE CONCEPT

A solution to these two problems is the microzone concept which is presented by Lee [Ref. 12] for the narrowband cellular systems. Microzone concept describes a cellular system that has been divided into smaller zones, usually three.

In this scheme, each of the three (it can be more than three zones when needed) zone sites are connected to a single base station and share the same radio equipment at the base station. The zones are connected by coaxial cable, fiberoptic cable, or

microwave link with the base station [Ref. 9].

Unlike the sectorized antennas analyzed in the previous chapter, the microzoning antennas are located at the edges of each of the zones, and hence at the outer perimeter of the cell. Microzoning antennas also differ from sectoring antennas in that they radiate back toward the interior of their cells. Each zone station has its own transmitter and receiver. The microzone concept as presented by Lee is shown in Figure 4.1.
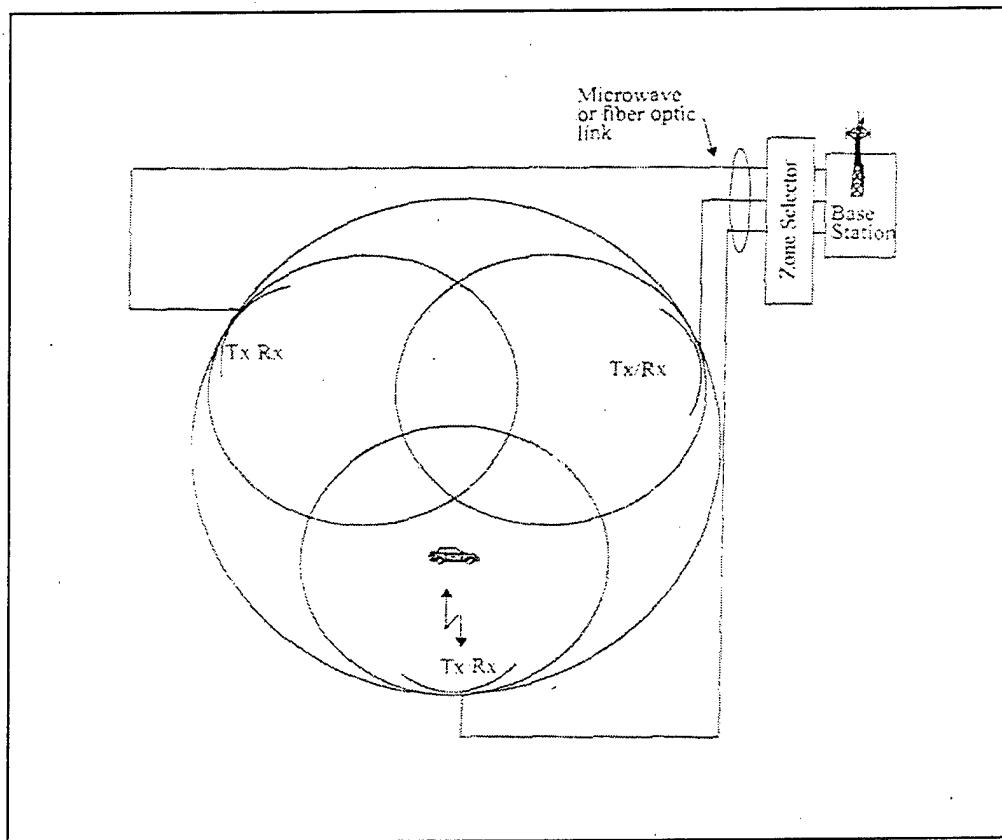

Figure 4.1: The microzone concept with three zone sites [Ref. 9].

The appropriate zone for each user is the zone that receives the mobile's signal the strongest. Only the appropriate zone station transmits to a specific user at a time in the forward link.

B. REVERSE LINK PROCESS

The reverse link is used when a mobile station in the cell sends a signal. Each zone site receives the signal and passes it through its up/down converter, up-converting the signal and sending it through either the microwave or optical signal medium, then down converting the signal at the base site. Thus, the mobile signals received from all zones are sent back to the base site. A zone selector located at the base site is used to select a proper zone to serve the mobile station by choosing the zone having the strongest signal strength. Then the base site delivers the cellular signal to the proper zone site through its up-converting processing [Ref. 12].

Thus, the microzone concept in the CDMA context allows for the mobile to stay on the same assigned code when it moves from zone to zone within a cell. The zone selector at the base site simply shifts the transmitting signal (base-to-mobile) from one zone to another zone according to the mobile station's location. Therefore, no softer handoff action is needed when the mobile station is entering a new active zone within a cell.

C. MICROZONE STRUCTURE AND ANTENNA PATTERN

In the microzone concept, we assume that each cell consists of 3 zones, that is, three "small hexagons" in this thesis (it can be more than 3 zones in a cell if needed). And, each zone site is located at the edge of its own zone, as shown in Figure 4.2.
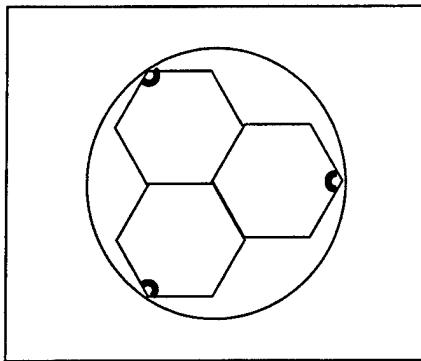
Figure 4.2: A cell with three zones.

To compare the signal to noise ratios of the microzone concept and the other two concepts (omni-directional and sectoring), we assume that each zone has the same size with the small hexagonal configuration given in the previous chapters.

In a microzone system, since each zone site has to cover only one "small hexagon", the microzone antenna height is always lower than 100 ft., normally 40 ft. to 50 ft., and generally the ground in a small area around the antenna is flat [Ref. 12]. Due to the small coverage area, the mobile stations need less power than the mobile stations mentioned earlier. The same is true for the zone stations used in a microzone system.

Under these conditions, we can assume that the interference effect of the second tier co-channel cells is also negligible. Thus, we will analyze only intracell interference and the first tier co-channel interference since the interference from the subsequent tiers is negligible as compared to the first tier. Using three zone layout, the reference cell and the adjacent first tier cells are shown in Figure 4.3.
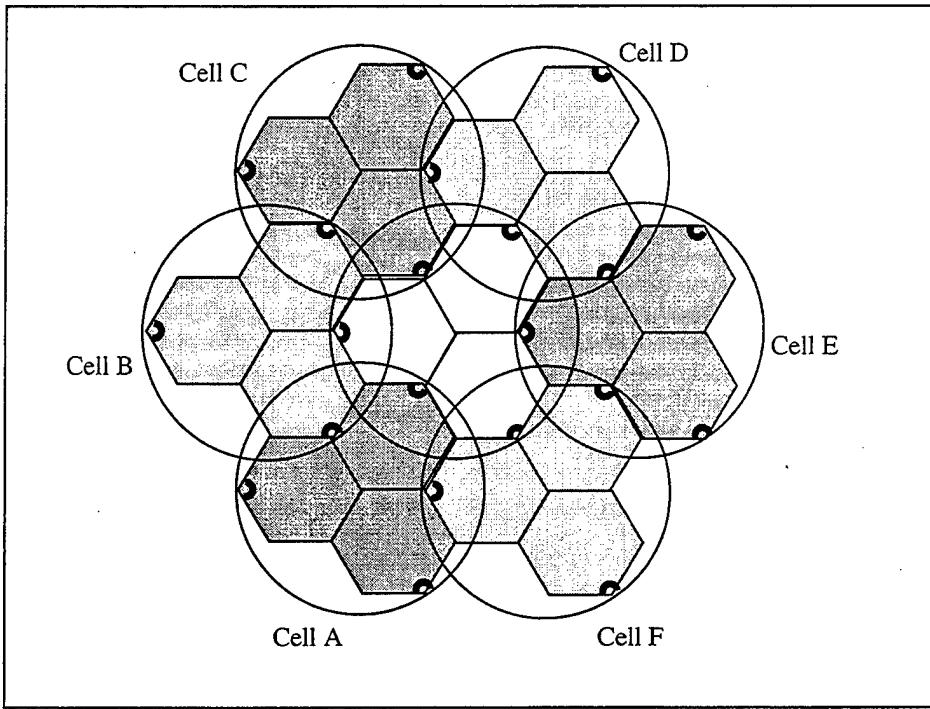
Figure 4.3: Three microzones per cell with the first tier co-channel cells.

In this figure, the zone antennas are designated by black semi-circles. Each zone antenna lies on the outer edge of its zone, and hence, the outer edge of its cell as well.

Referring to [Ref. 12], the antenna pattern for each zone coverage is 160^0 as shown in Figure 4.4.
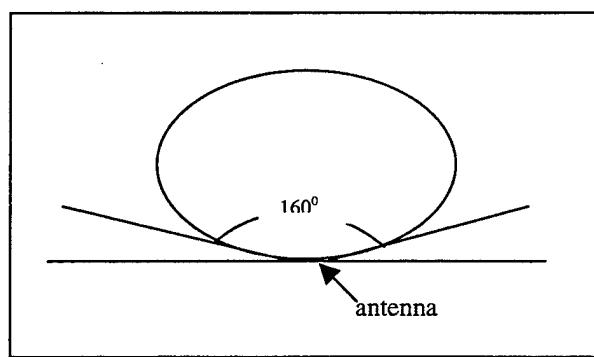

Figure 4.4: microzone station antenna pattern.

Using the 160^0 antenna pattern as depicted in Figure 4, the three zones per cell system is illustrated in Figure 4.5. Thus, the entire cell is covered.
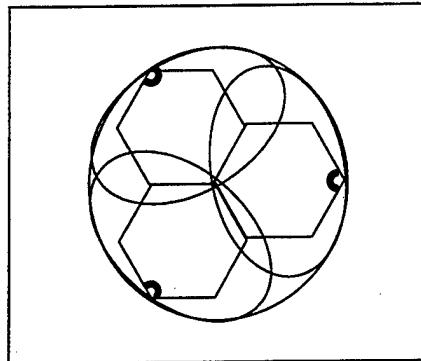
Figure 4.5: The three zone per cell system with 160^0 antenna pattern.

D. SIGNAL TO INTERFERENCE RATIO

Equation 2.1 will be used for finding the signal to interference ratio (SIR) for all architecture presented in this chapter. The additive white Gaussian noise term within the reference cell will remain the same as in the previous chapters. Distances will be given in terms of R_z, the zone radius. Again, due to the minor effect of the second-tier co-channel interferers, only the first-tier co-channel interfering cells will be considering.

Since each zone station covers all its own cell area, the microzoning system looks like the omni-directional antenna system for the intra-cell interference as in the Chapter II. Thus, using (2.6), we obtain the second term of (2.1) which is the intra-cell signal to interference ratio for the microzoning system as

$$\left(\frac{S}{I}\right)^{-1}_{m_{in-cell}} = \frac{2(K_m - 1)\alpha}{3N} , \tag{4.1}$$

where K_m is the number of mobile stations in the reference cell, α is the channel activity factor, and N is the spreading factor.

The third term in (2.1) is the first tier co-channel interference at the zone station of interest. Before we evaluate the signal to interference ratio of the first-tier co-channel

40

cells, we should obtain the interfering cells and the distances between the interfering

mobile stations and the reference zone station.

The illustration of the reference cell and the zone station employing 160^0

directional antenna system with the first tier co-channel cells is shown in Figure 4.6

below. The distances between the reference zone station and the interfering mobile

stations of the first tier co-channel cells in a three-zone per cell layout are also depicted.
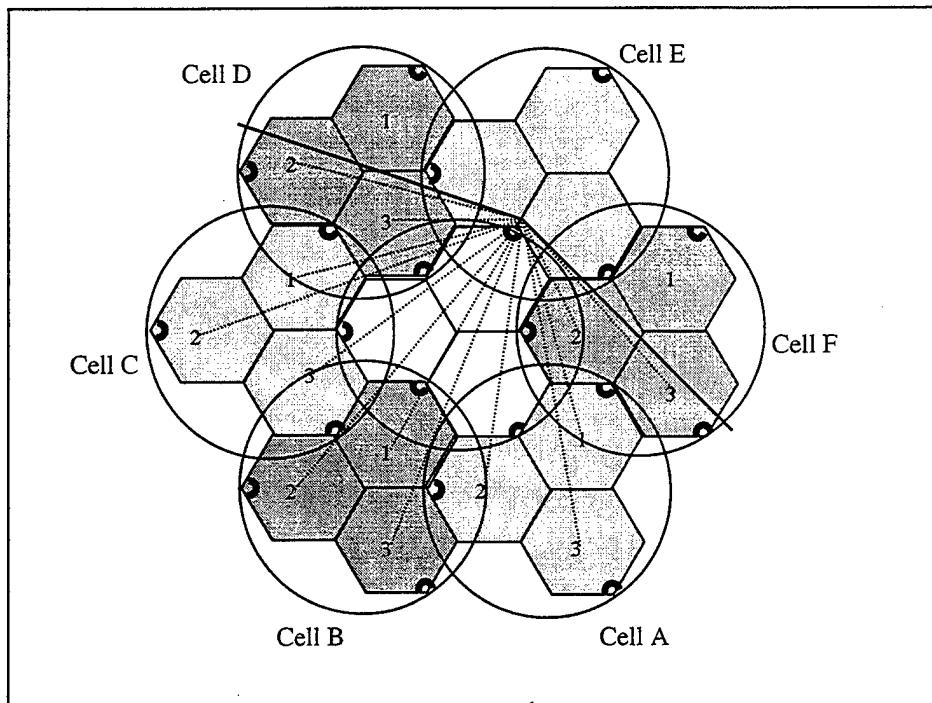
Figure 4.6: The distances between the reference zone station and the interfering users.

In this figure, the reference (top most) zone antenna radiates back toward the

center of the cell with a 160^0 radiation pattern. The reference cell is the center cell. The

surrounding cells are the first tier co-channel cells denoted by A through F. From the

Figure 4.6, we notice that the cells A, B, C, and the zones D_2, D_3, F_2, and F_3 are the first

tier co-channel interfering cells/zones since they are in the coverage area of the reference

zone station. We also notice that all the mobile stations have omni-directional antennas

although the zone stations have 160^0 directional antenna.

The distances from the reference zone station to the interfering mobile stations which are located at the center of the zones in the cells A, C , and also D and C are equal. That is, $d_{A1}=d_{C1}$, $d_{A2}=d_{C3}$, $d_{A3}=d_{C2}$, $d_{D2}=d_{F3}$, and $d_{D3}=d_{F2}$.

Assuming R_z is the zone radius, and using (2.9) we obtain the distances as

$d_{A1}=d_{C1}=\sqrt{13}R_z$, $d_{A2}=d_{C3}=\sqrt{19}R_z$, $d_{A3}=d_{C2}=2\sqrt{7}R_z$, $d_{B1}=4R_z$, $d_{B2}=d_{B3}=\sqrt{31}R_z$,

$d_{D2}=d_{F3}=\sqrt{13}R_z$, and $d_{D3}=d_{F2}=2R_z$. We also notice that the distance between each mobile station and its zone station is R_z.

Using (2.17) and (2.7), we obtain the third term of (2.1) which is the first tier co-channel signal to interference ratio for the microzoning system as

$$\left(\frac{S}{I}\right)^{-1}_{m_{tier-1}} = \frac{2\alpha}{3N}\left[2\sum_{i=1}^{3}K_{A_i}\left(\frac{d_{A_i}}{R_z}\right)^{-n} + \sum_{i=1}^{3}K_{B_i}\left(\frac{d_{B_i}}{R_z}\right)^{-n} + 2\sum_{i=2}^{3}K_{D_i}\left(\frac{d_{D_i}}{R_z}\right)^{-n}\right], \quad (4.2)$$

and using the normalized distances $D_{A_i} = d_{A_i}/R_z$, $D_{B_i} = d_{B_i}/R_z$, and $D_{D_i} = d_{D_i}/R_z$, we get

$$\left(\frac{S}{I}\right)^{-1}_{m_{tier-1}} = \frac{2\alpha}{3N}\left[2\sum_{i=1}^{3}K_{A_i}D_{A_i}^{-n} + \sum_{i=1}^{3}K_{B_i}D_{B_i}^{-n} + 2\sum_{i=2}^{3}K_{D_i}D_{D_i}^{-n}\right], \quad (4.3)$$

where K_{A_i}, K_{B_i}, and K_{D_i} are the number of mobile stations in the corresponding zones of the cells, and D_{A_i}, D_{B_i}, and D_{D_i} are the normalized distances between the corresponding mobile stations and the reference zone station.

Substituting (4.1) and (4.3) into (2.1), we obtain the signal to interference ratio of the microzoning system as

$$\left(\frac{S}{I}\right)_m = \left[\left(\frac{E_b}{N_0}\right)^{-1} + \frac{2\alpha}{3N}\left((K_m - 1) + 2\sum_{i=1}^{3} K_{A_i} D_{A_i}^{-n} + \sum_{i=1}^{3} K_{B_i} D_{B_i}^{-n} + 2\sum_{i=1}^{2} K_{D_i} D_{D_i}^{-n}\right)\right]^{-1} . \quad (4.4)$$

E. REDUCTION OF THE HANDOFFS

As mentioned before, within each cell, no handoffs (softer handoffs) from zone-to-zone are needed. Zone-to-zone switching are handled by a zone selector. The active zone follows the mobile unit as it moves from one zone to another.

In this section we will roughly estimate how many handoffs can be eliminated relative to a regular cell in which three sectors are used. In a regular cell, if we use 120^0 sectoring there are three sectors. The mobile station can move in any one of four directions, as shown in Figure 4.7 [Ref. 12].
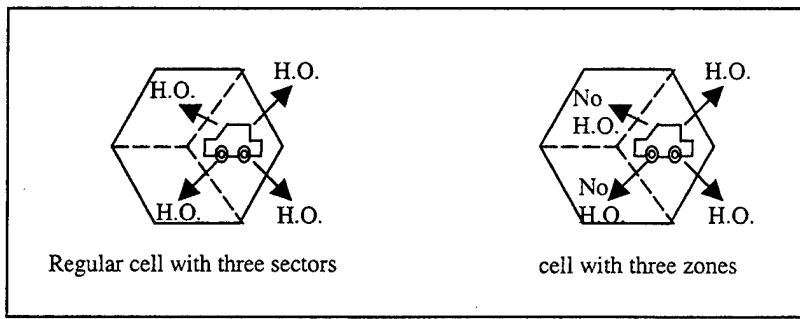
Figure 4.7: Reduction of handoffs in microzoning systems [Ref. 12].

When a mobile station moves through the other two sectors, it needs handoffs. When it enters, as well as when moving out of a cell, a handoff occurs. In the microzoning system, a mobile station moving to either of the other two zones does not need handoffs. A handoff only occurs when the mobile station moves in or out of the cell. Therefore, we may estimate that only one half of the handoffs required in a regular sectoring system will occur in a microzoning system. This reduction in handoffs in the microzoning system is a great contribution to the system capacity.

F. SYSTEM CAPACITY AND ADVANTAGES OF THE MICROZONING SYSTEM

In any cellular system, system capacity is the overall capacity, and can differ from system to system. System capacity may be capped by three limiting elements: radio capacity, control link capacity, and switch capacity, as shown in Figure 4.8 [Ref. 12].
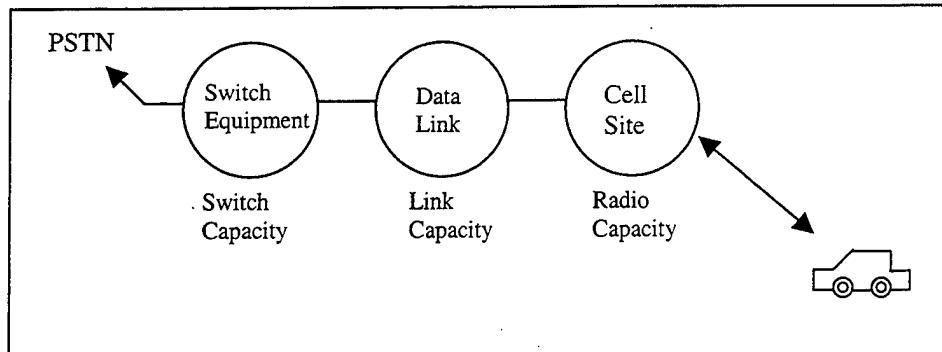

Figure 4.8: Three bottlenecks of the Cellular Systems [Ref. 12].

The radio capacity is the element most often addressed in the public domain. The link capacity and switch capacity are the two elements often overlooked in measuring system capacity. Control link capacity measures the capacity of the fast control link between the cell site and the switches. If the number of microwave links or T1 carrier lines are not sufficient, a bottleneck will result. Switch capacity measures the capacity of traffic at the switching office. Again, if the switch is not big enough to handle the radio capacity, a bottleneck problem occurs.

Among these three elements (capacities), the weakest element must be used to gauge the system's capacity. Therefore, improving the radio capacity in the system may not be enough. Improving system capacity requires upgrading the lowest capacity of the three. With this in mind, every system operator should be aware that radio capacity is not the entire problem nor the entire solution.

As mentioned before, in a microzoning system, since fewer soft/softer handoffs are needed as compared to the sectoring or omni-directional system, both the switching load and the control link load are cut roughly by half. The easing of half the load means twice the load can be added back onto the system. The roughly doubled radio capacity is what the microzoning systems offer without changing the present switching equipment.

Another advantage of the microzoning system is the increase of the probability of signal reception. The three zone stations receiving the mobile signal simultaneously from three zones form a three-branch different-site diversity that is suitable for low-power portable units. It tends to increase the probability of signal reception at the base station due to diversity.

V.   NUMERICAL ANALYSIS

Now that the expressions have been derived for the signal to interference plus noise ratio, specific comparisons can be performed between the different systems. The analysis of the omni-directional, sectoring (60^0 and 120^0), and microzoning architectures in the CDMA systems will be presented. Finally, the performance and capacity comparisons of these architectures will be shown.

The basic equation used for finding the signal to interference plus noise ratio is equation 2.1. This equation includes AWGN, intracell interference, also known as the multiuser interference within the reference cell, first tier co-channel multiuser interference, and the second tier co-channel multiuser interference.

A. SPECIFIC PARAMETERS FOR SIGNAL TO INTERFERENCE RATIO ANALYSIS

Specific values will be substituted for each of the parameters derived in Chapters II, III, and IV to enable a direct comparison between the different architectures by way of plots of overall SIR as a function of E_b/N_0 for the performance analysis and the plots of overall SIR as a function of number of users per cell (K) or number of users per small hexagon/zone (K_i) for the capacity analysis.

These variable parameters are the path loss exponent (n) which indicates the rate at which the received power decreases while the distance increases, and typically ranges between 2 and 4 in urban cellular systems (the values of n are 3 and 4 in our simulations), spreading factor or processing gain (N), channel (voice) activity factor (α), number of users per cell or small hexagon/zone (K or K_i respectively), and the overlap angle for the sectoring architecture.

47

Each plot in this chapter lists the parameters being used. The specific architectures shown on each plot are listed in the legend. In accordance with industry's push toward a Third Generation Standard, a processing gain of 128 is generally used.

Although the path loss exponents were kept consistent for the reference cell and all co-channel cells within each case study, the program can accept a unique input for each path loss exponent for every cell. The same is true for the number of users per cell or small hexagon/zone. Each cell or small hexagon/zone can have a different number of users. The specific cases shown were chosen to represent some typical situations without inundating the reader with endless combinations of specific values for variables.

B. INTERPRETATION OF RESULTS

A path loss exponent of 3 or 4 is used in the subplots for each Figure. In Figures 5.1-5.5, the signal to interference ratio versus E_b/N_0 plots of the omni-directional antenna system are displayed using number of users per cell of 56, spreading factors of 64, 128, 256, and 512, and channel activity factors of 0.2, 0.4, 0.6, 0.8, and 1. As expected, when we increase the spreading factor or decrease the channel activity factor, we get better performance. And, we can also expect that the performance of the system using path loss exponent of 4 is better than the performance of the system using path loss exponent of 3. Since the cases presented here assign the same path loss exponent to the reference cell and all the co-channel cells, the penalty for having a higher path loss exponent in the reference cell is outweighed by the fact that all of the interfering cells also have a higher path loss exponent. This results in more attenuation of the transmissions from the co-channel cells, and hence, lowers interference.

In Figures 5.6-5.10, the performance analysis is shown using the number of users per cell of 112, while keeping other parameters the same. When we increase the number of users per cell, we get a worse performance due to the increasing interference at the reference base station.

In Figures 5.11 and 5.12, the system capacity (signal to interference ratio versus number of users per cell) of CDMA employing omni-directional antenna is displayed using E_b/N_0 of 25 dB, channel activity factors of 0.2, 0.4, 0.6, 0.8, 1, and the spreading factors of 128, and 256, respectively. We get more than 5 dB SIR which is enough for the third generation CDMA system, between the range of 120-140 users per cell for the channel activity factor of 0.2, and 0.4.

In Figures 5.13-5.15, the performance of CDMA system employing sectoring using 60^0 and 120^0 antenna pattern is displayed with the number of users per cell of 56, spreading factors of 64, 128, 256, and 512, path loss exponent of 4, channel activity factor of 0.4, and the overlap angles of 0 (perfect sectoring), 10, and 20, respectively. As expected, the performance of 60^0 sectoring is better than the performance of 120^0 sectoring due to less number of users, that is less interference, per sector. But in practice, an increase in the number of sectors will cause more switching and an increased control link load since more softer handoffs are needed.

In Figures 5.16-5.21, the system capacity of CDMA system employing sectoring using 60^0 and 120^0 antenna patterns is displayed using E_b/N_0 of 25 dB, spreading factors of 128, and 256, path loss exponent of 4, channel activity factors of 0.2, 0.4, 0.6, 0.8, 1, and the overlap angles of 0 (perfect sectoring), 10, and 20, respectively. We get more than 10 dB SIR in 60^0 sectoring, and more than 8 dB SIR in 120^0 sectoring, with 200

users per cell, using spreading factor of 128, channel activity factors of 0.2, and 0.4, and the overlap angle of 0.

In Figures 5.22-5.24, the performance of the CDMA system employing microzoning concept is displayed with the number of users per cell of 24 (8 users per zone), spreading factors of 64, 128, 256, and 512, and channel activity factors of 0.2, 0.4, and 0.6. Again, as expected, when we increase the spreading factor or decrease the channel activity factor, we get better performance. And, we can also see that the performance of the system using a path loss exponent of 4 is better than the performance of the system using a path loss exponent of 3.

In Figures 5.25 and 5.26, the system capacity of the CDMA system employing microzoning concept is displayed using an E_b/N_0 of 25 dB, spreading factor of 128, and 256, and channel activity factors of 0.2, 0.4, 0.6, 0.8, 1. We obtain a SIR value greater than 5 dB, between the range of 140-160 users per cell, using spreading factor of 128, channel activity factors of 0.2, and 0.4.

In Figures 5.27-5.29, the performance comparisons of three configurations (omni-directional antenna pattern, sectoring with 60^0 and 120^0, and microzoning) are shown with a spreading factor of 128, number of users per small hexagon/zone of 8 (56 users per cell or 24 users per microzoning cell), and path loss exponent of 0.4. Using perfect sectoring, an E_b/N_0 of 30 dB, and path loss exponent of 3, we obtained the following results: At 60^0 sectoring, the SIR is 15.8 dB, at 120^0 sectoring and microzoning (almost the same) the SIR is 12.5 dB, and finally, in the omni-directional system the SIR is 7.8 dB. When we increase the path loss exponent from 3 to 4, we get slightly higher increase in the performance of the microzoning system than the other configurations. We obtain

the following results: At 60^0 sectoring, the SIR is 16.5 dB, in microzoning system, the SIR is 13.4 dB, at 120^0 sectoring, the SIR is 13 dB, and finally, in the omni-directional system the SIR is 8.5 dB.

As expected, a larger overlap angle will cause the decrease of performance in the sectoring system. This effect is shown in Figures 5.28 and 5.29 using overlap angles of 10 and 20, respectively. Also, although 60^0 sectoring seems to have better performance than the microzoning system in the simulation results. In a microzoning system, since fewer soft/softer handoffs are needed as compared to the sectoring or omni-directional system, both the switching load and the control link load are cut roughly by half.

In Figures 5.30-5.32, the capacity comparisons of three configurations are displayed using an E_b/N_0 of 25 dB, spreading factor of 128, and path loss exponent of 0.4. We can reach similar conclusions as in the previous two paragraphs.

As expected for all architectures, the best performance occurs with the least number of users per cell. Typically, the intracell interference due to multiple users operating within the same cell is limiting factor in the number of users per cell a system can support. Also, the larger spreading factor, the more users per cell that can be supported at the same SIR.
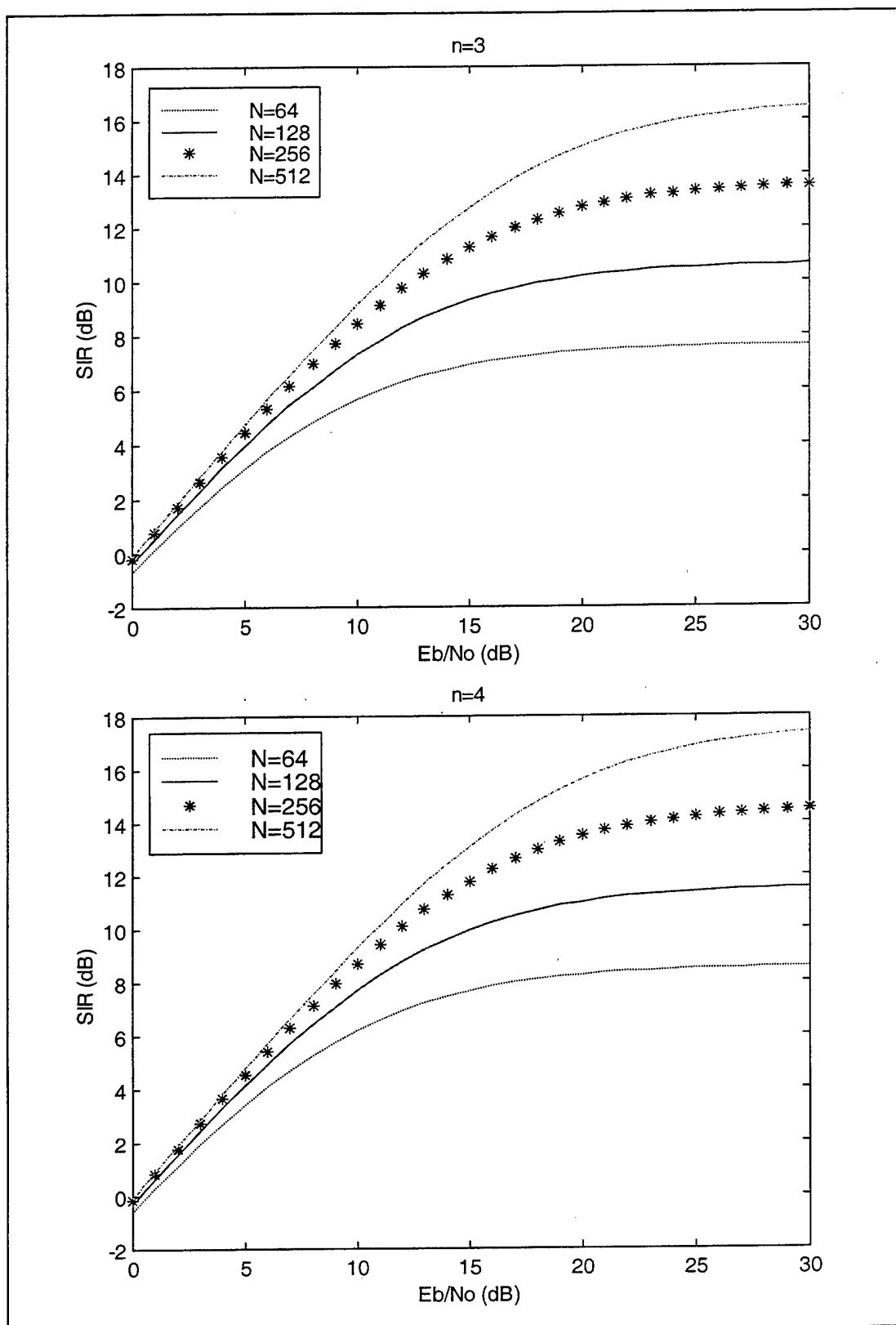
Figure 5.1: The Performance of the CDMA System Employing Omni-directional
Antennas with $\alpha = 0.2$ and K=56.
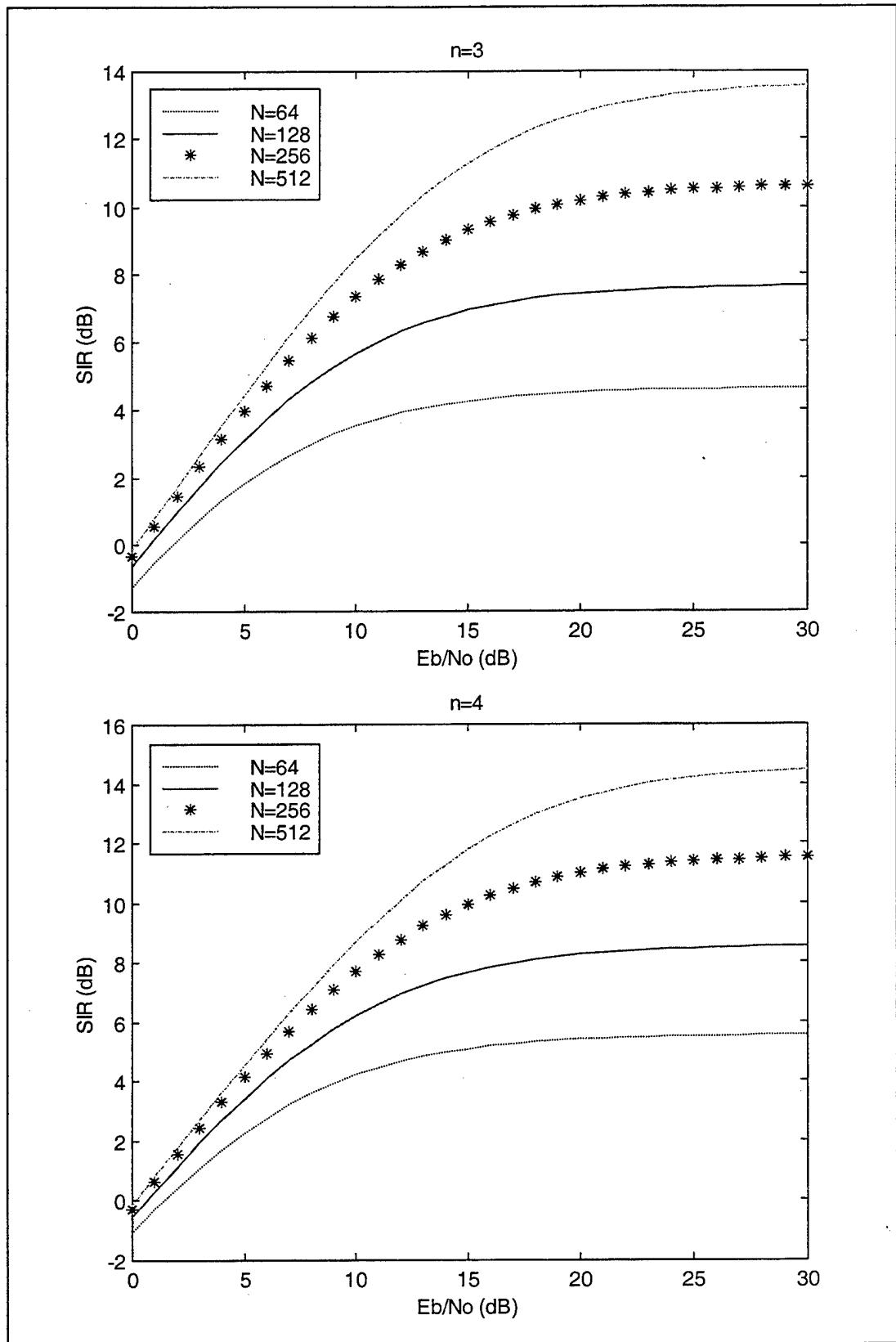
Figure 5.2: The Performance of the CDMA System Employing Omni-directional
Antennas with $\alpha = 0.4$ and K=56.
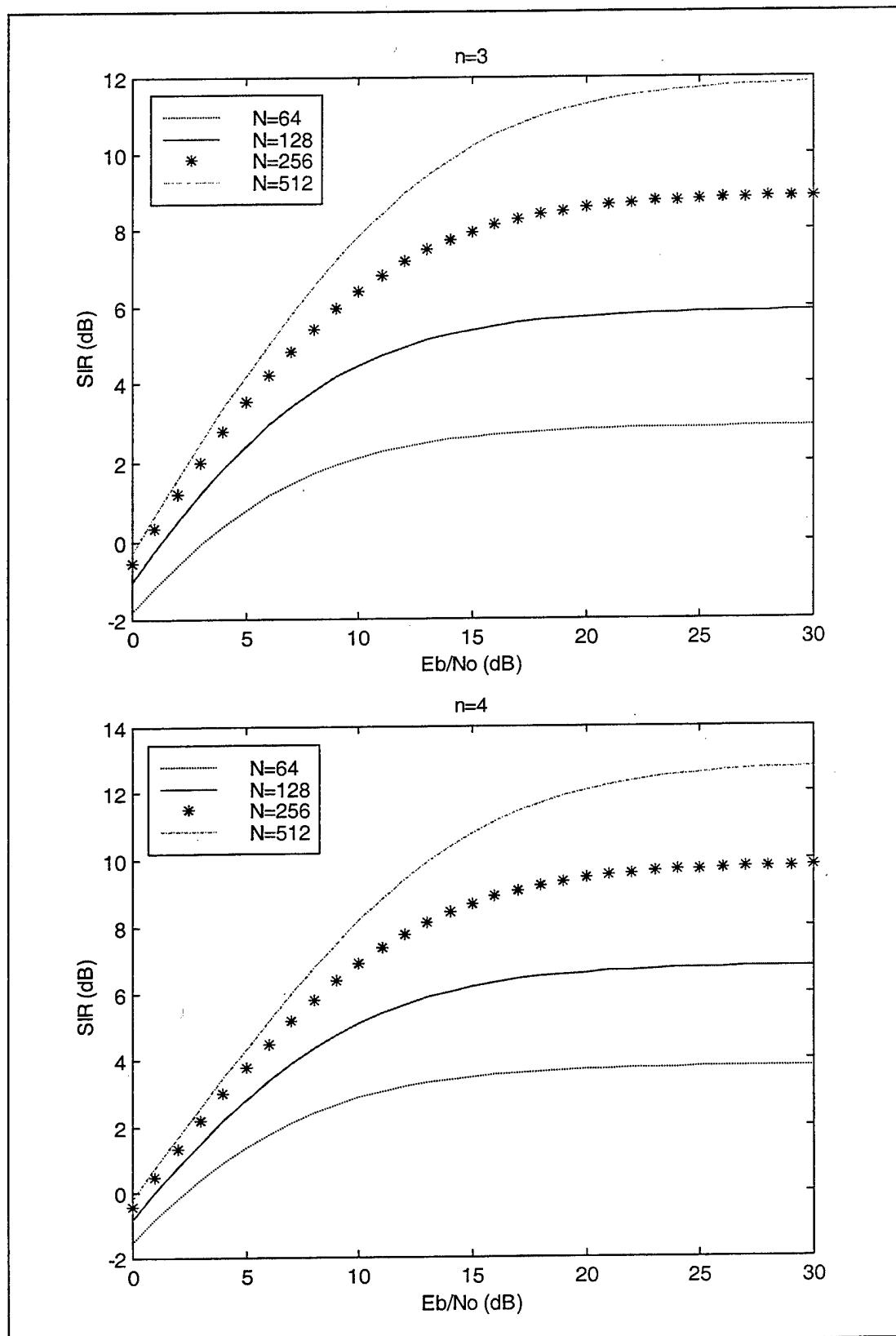
Figure 5.3: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 0.6$ and K=56.
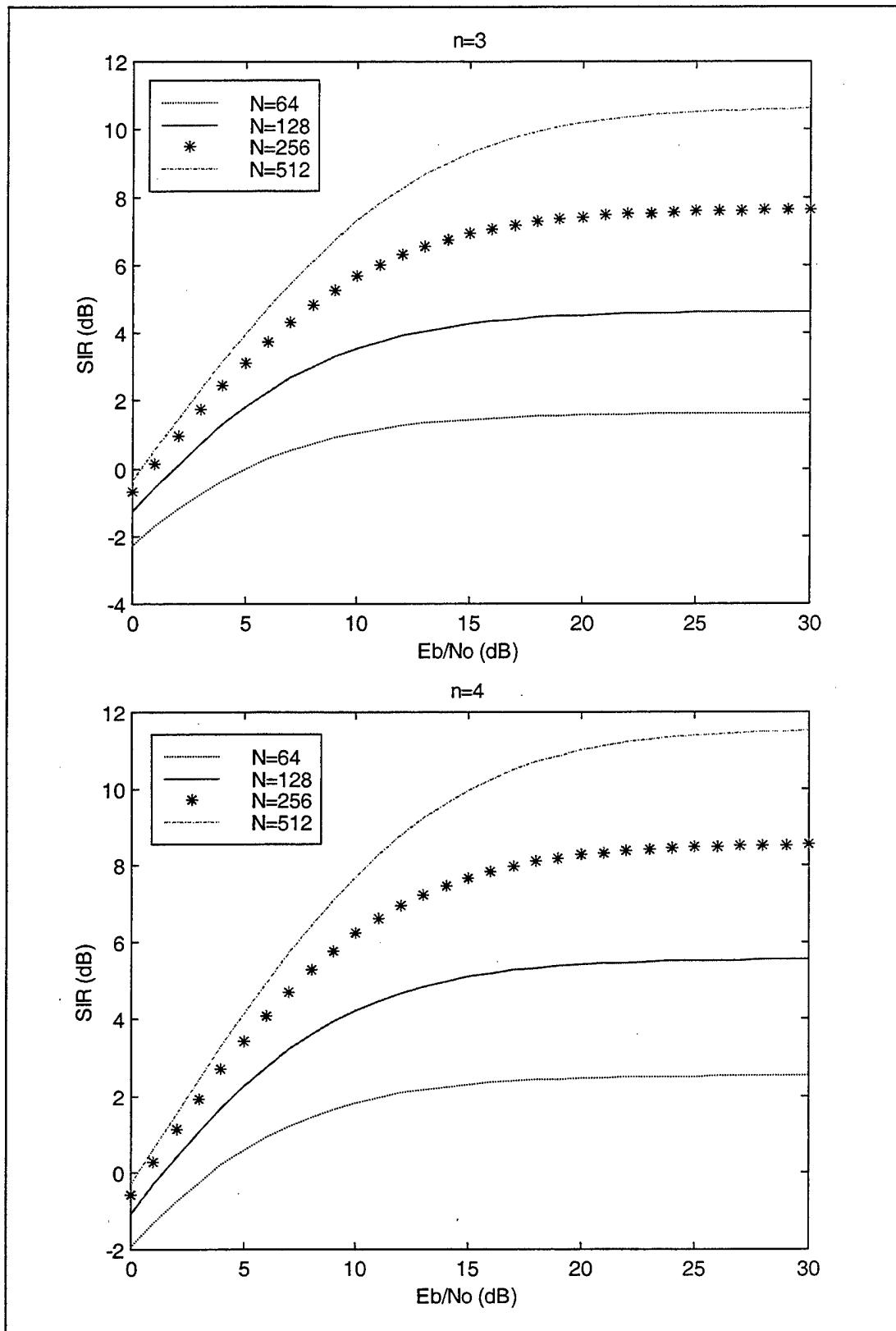
Figure 5.4: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 0.8$ and K=56.
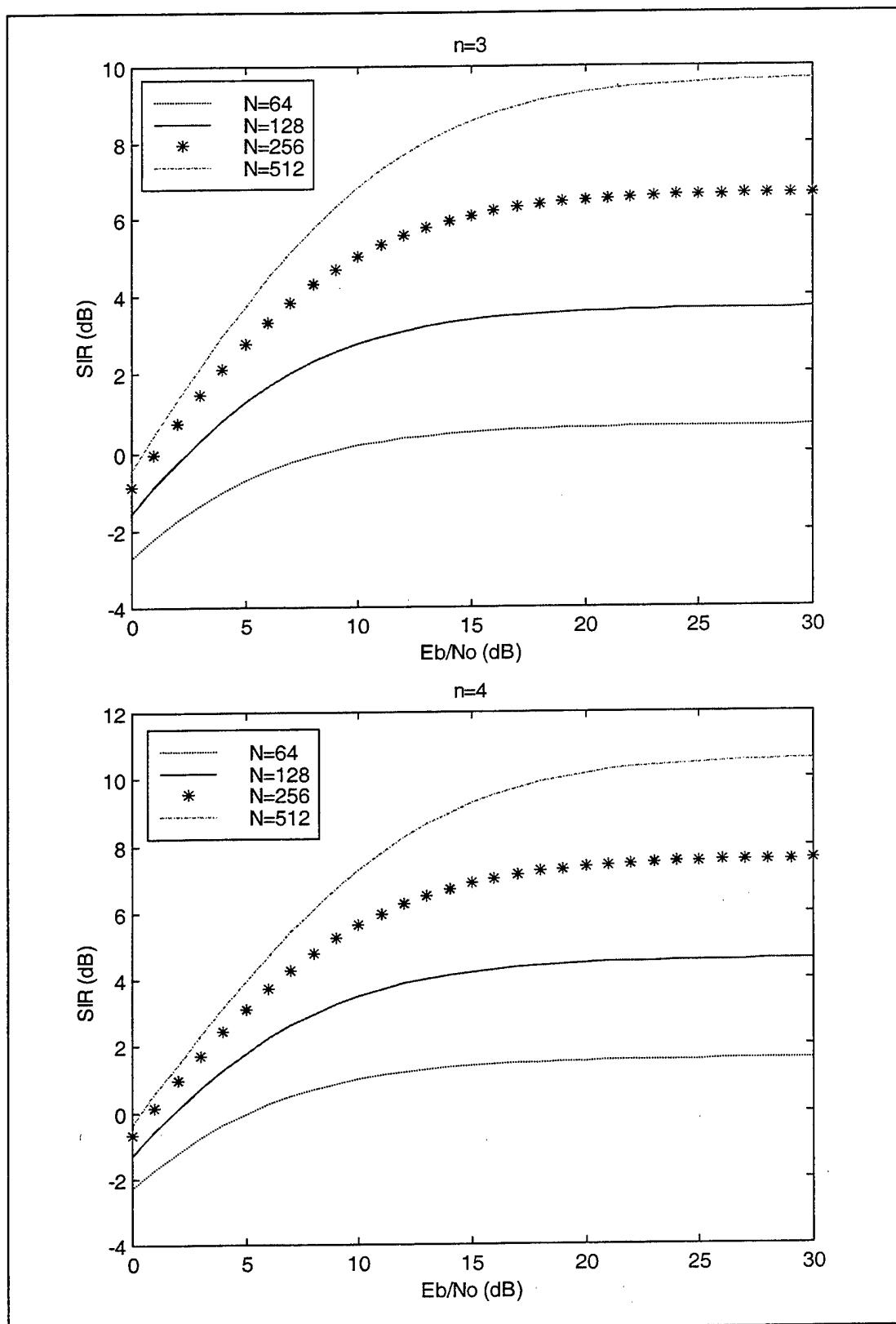
Figure 5.5: The Performance of the CDMA System Employing Omni-directional
Antennas with $\alpha = 1$ and K=56.
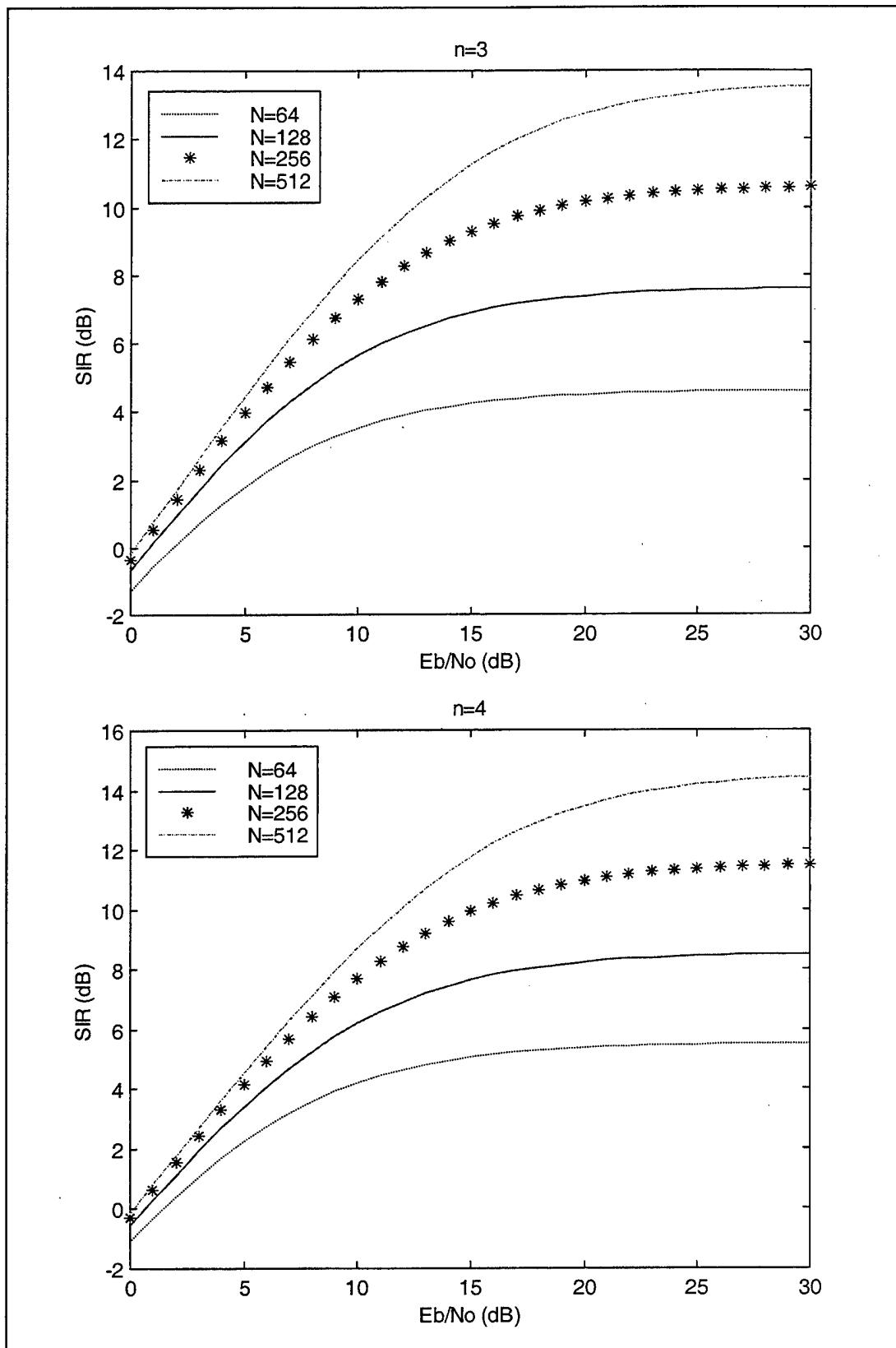
Figure 5.6: The Performance of the CDMA System Employing Omni-directional
Antennas with $\alpha = 0.2$ and K=112.
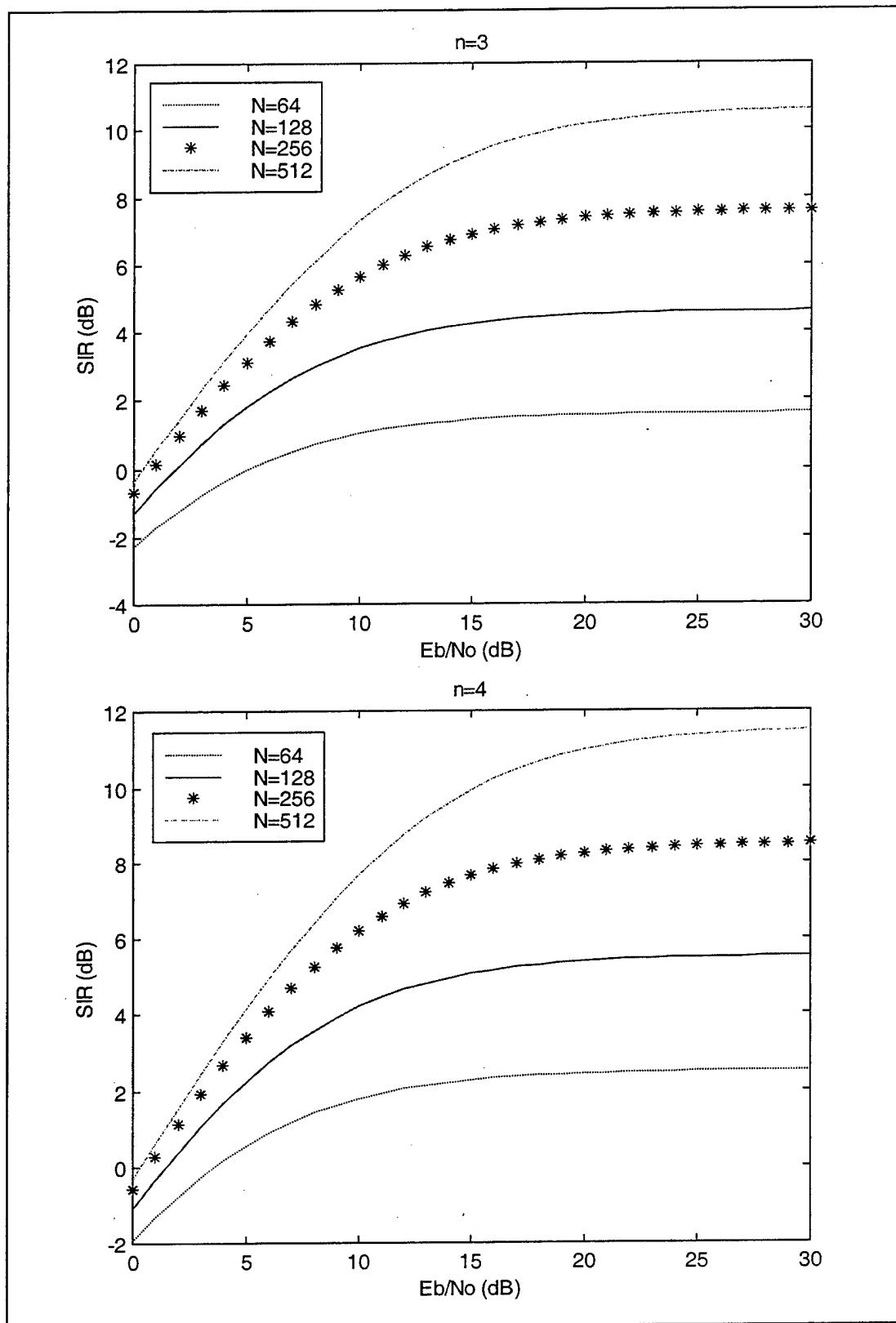
Figure 5.7: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 0.4$ and K=112.
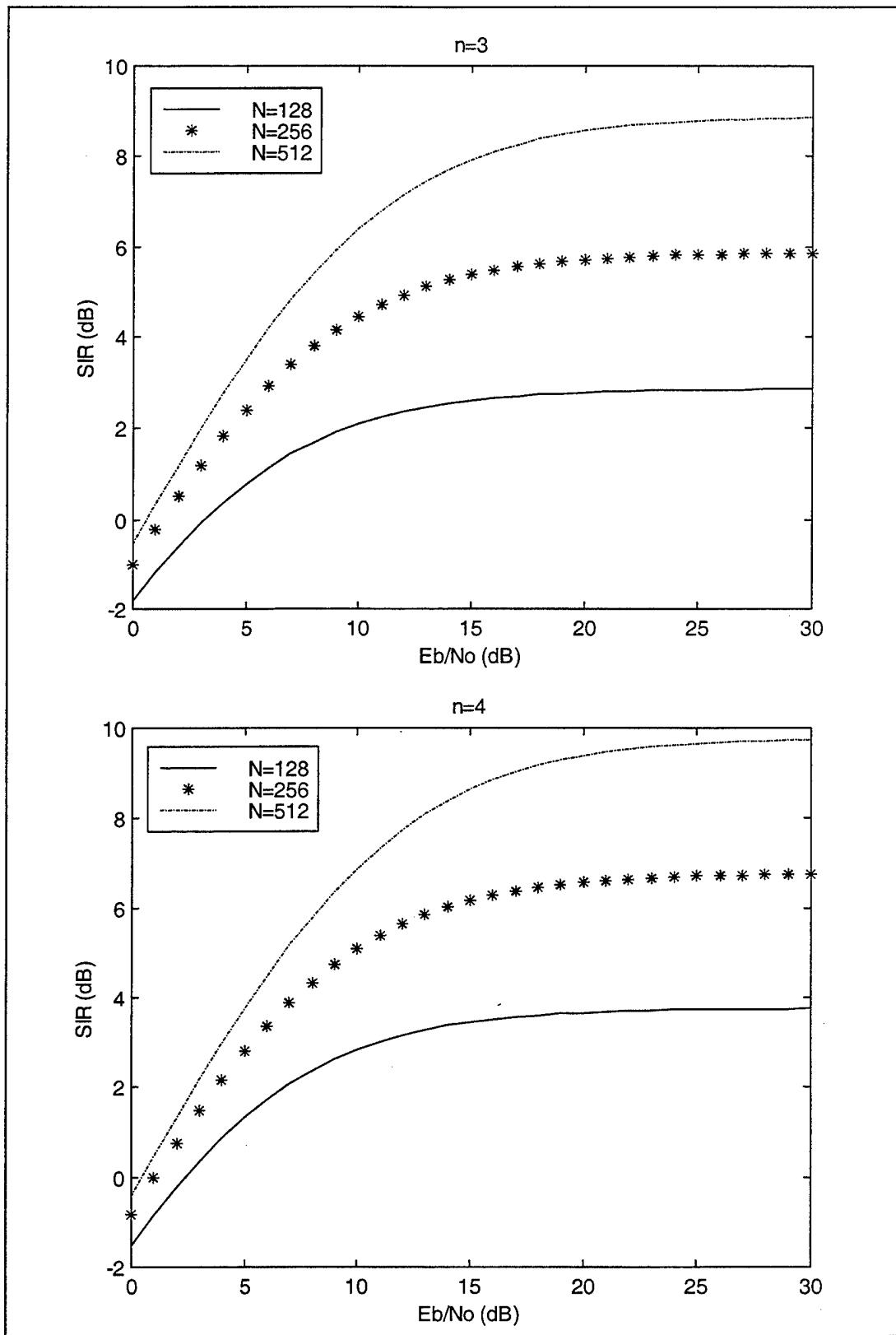
Figure 5.8: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 0.6$ and K=112.
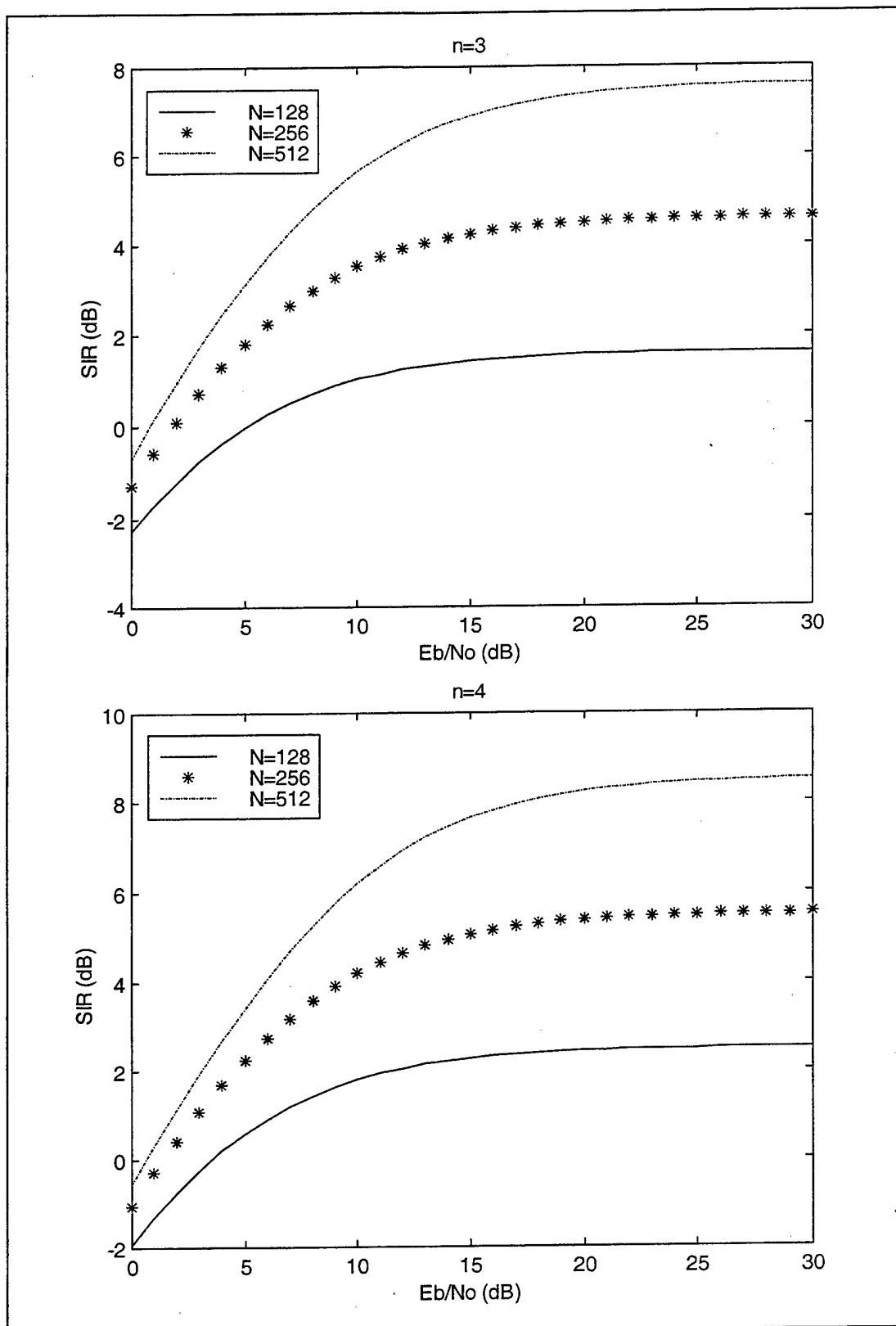
Figure 5.9: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 0.8$ and K=112.
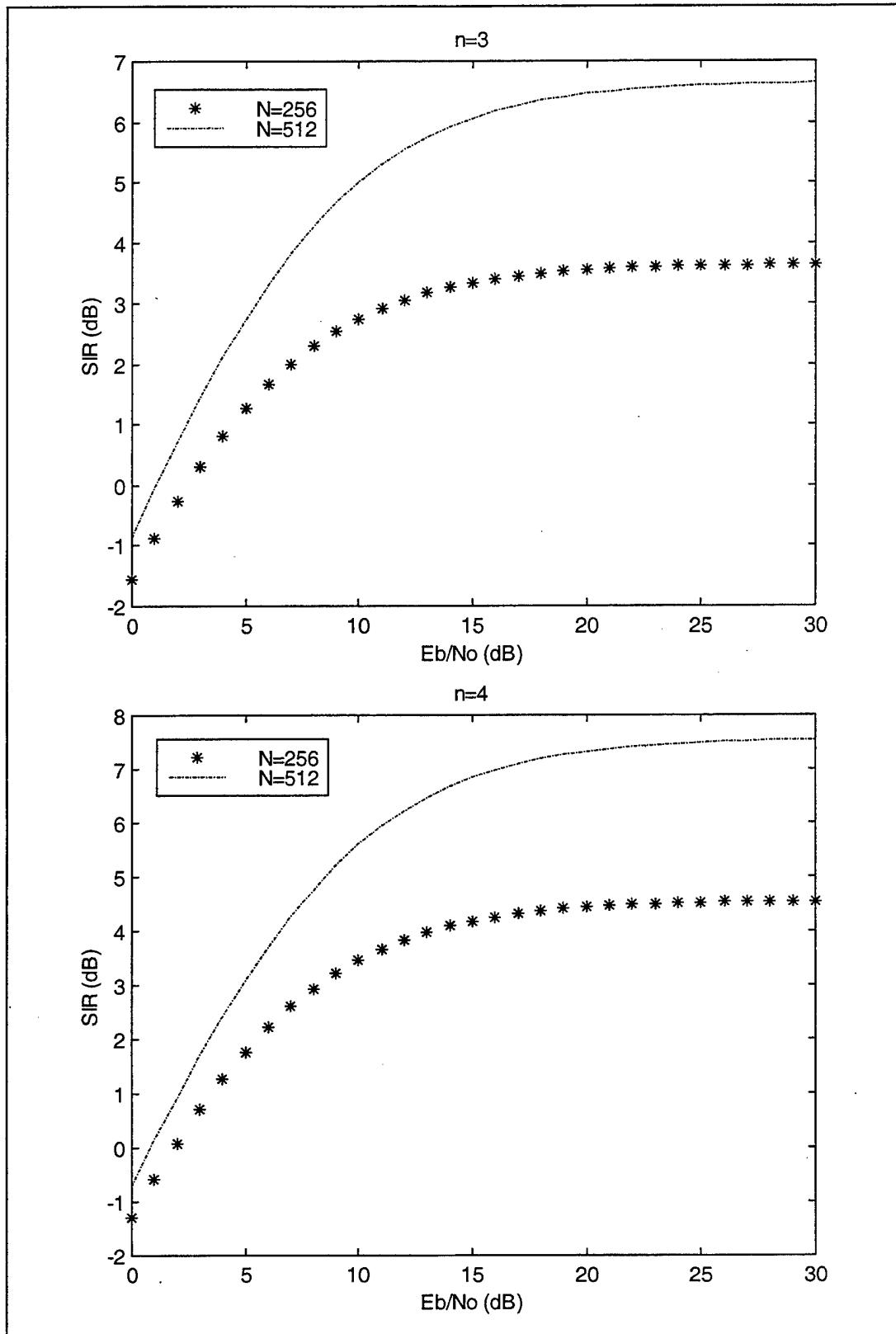
Figure 5.10: The Performance of the CDMA System Employing Omni-directional Antennas with $\alpha = 1$ and K=112.
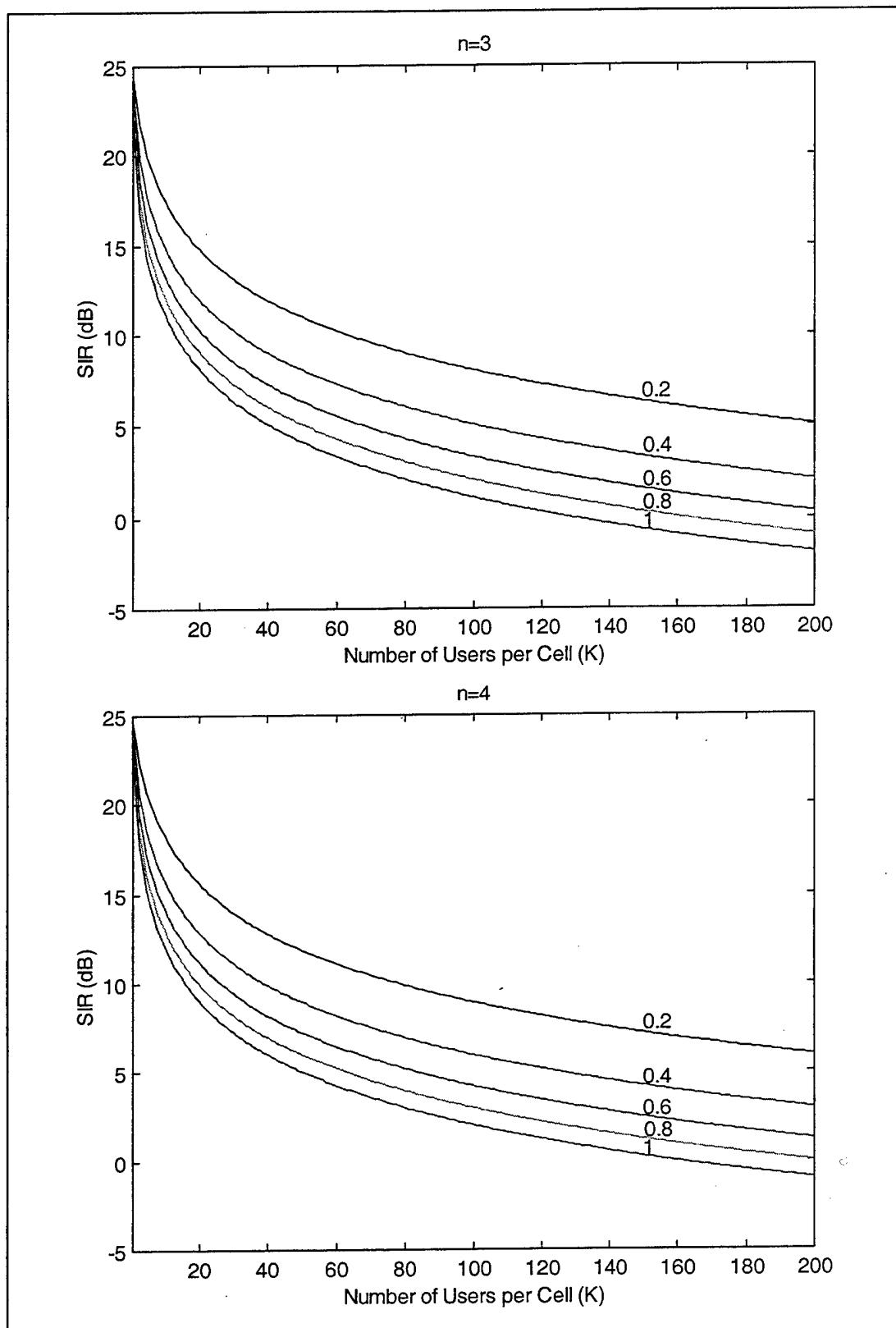
Figure 5.11: The System Capacity of the CDMA, Employing Omni-directional Antennas with Spreading Factor of 128, Eb/No=25 dB, and α =0.2, 0.4, 0.6, 0.8, 1.
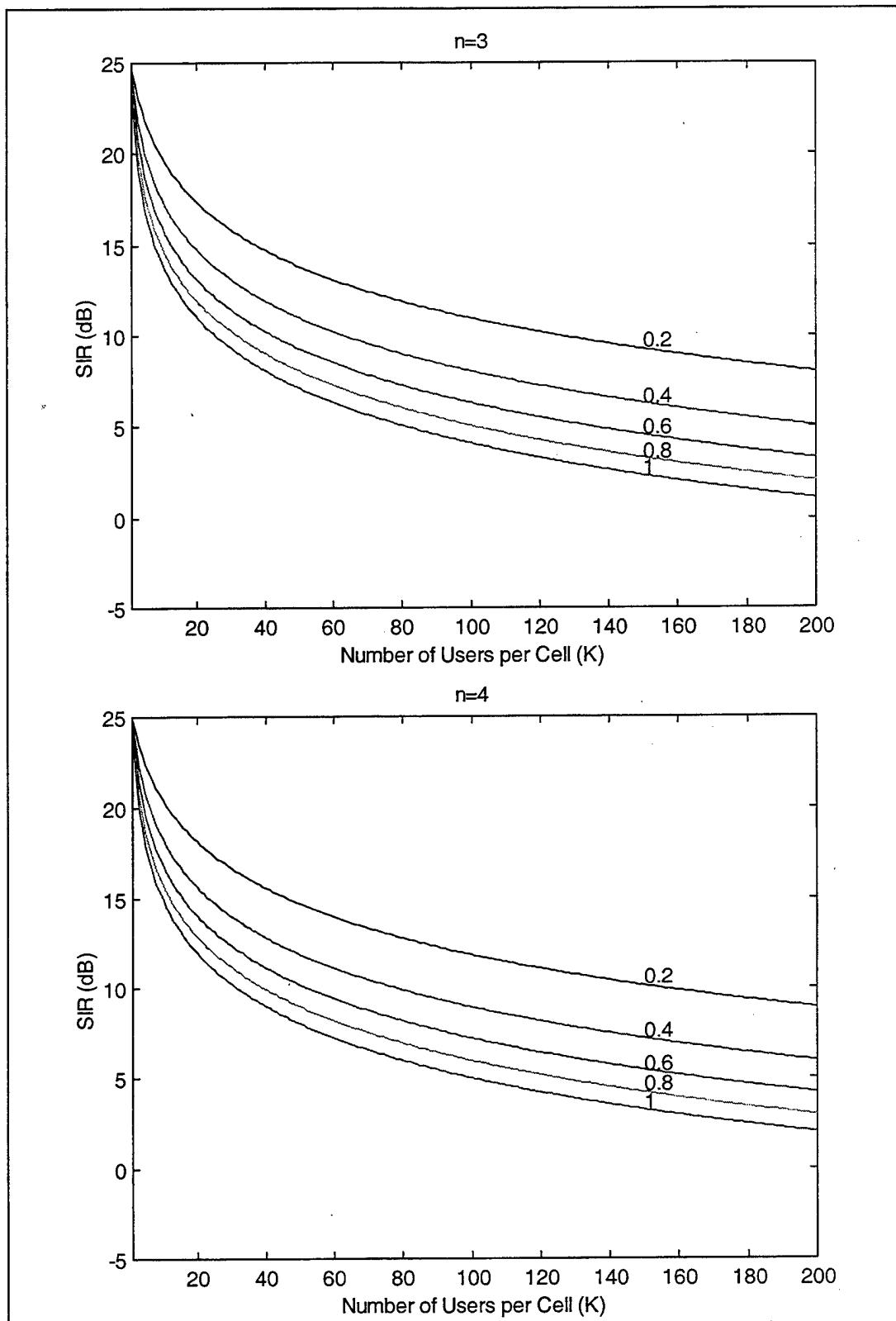
Figure 5.12: The System Capacity of the CDMA, Employing Omni-directional Antennas with Spreading Factor of 256, Eb/No=25 dB, and α =0.2, 0.4, 0.6, 0.8, 1.
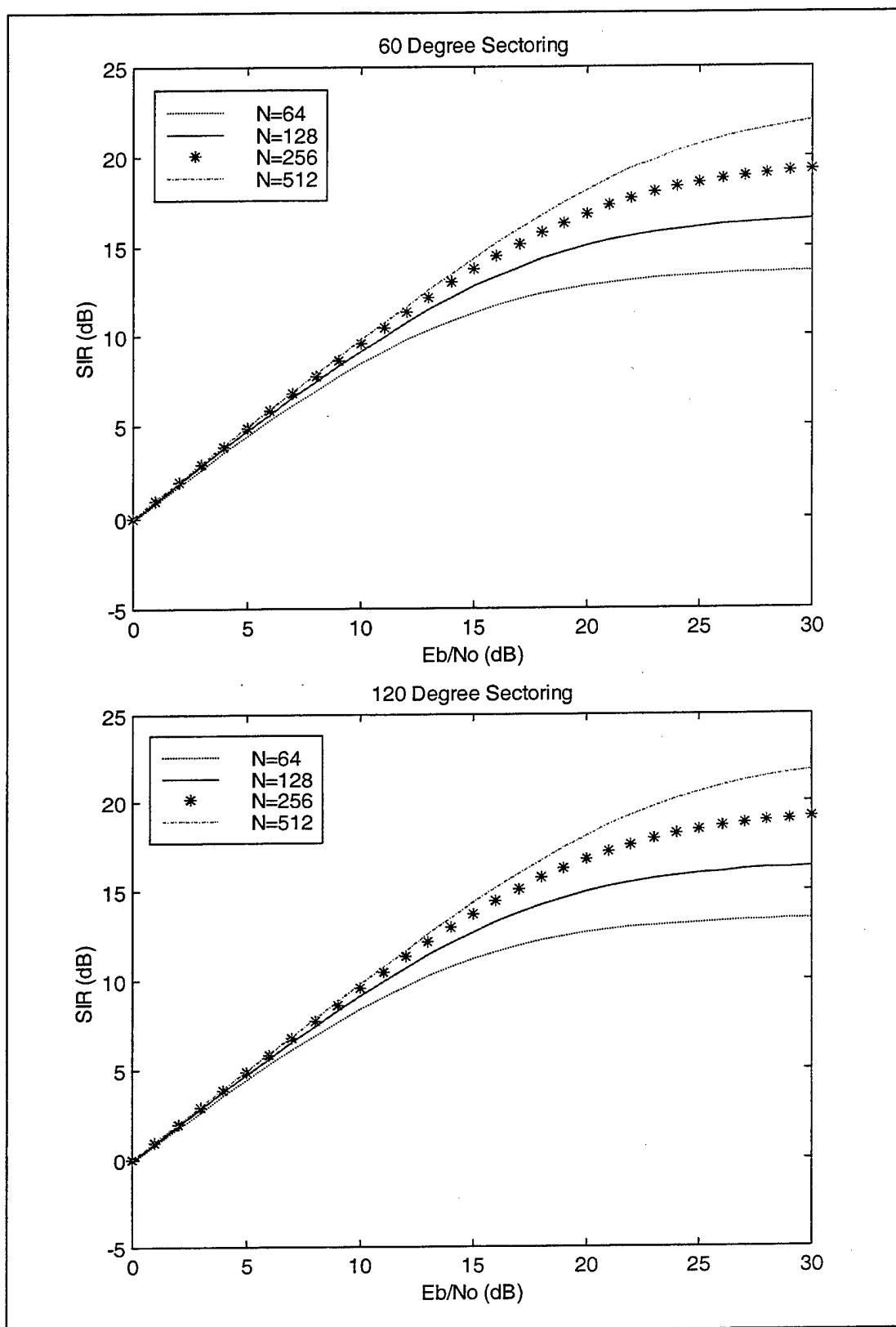
Figure 5.13: The Performance of the CDMA System Employing Sectoring with Overlap Angle of 0 (Perfect Sectoring), K=56, n=4, and α =0.4.
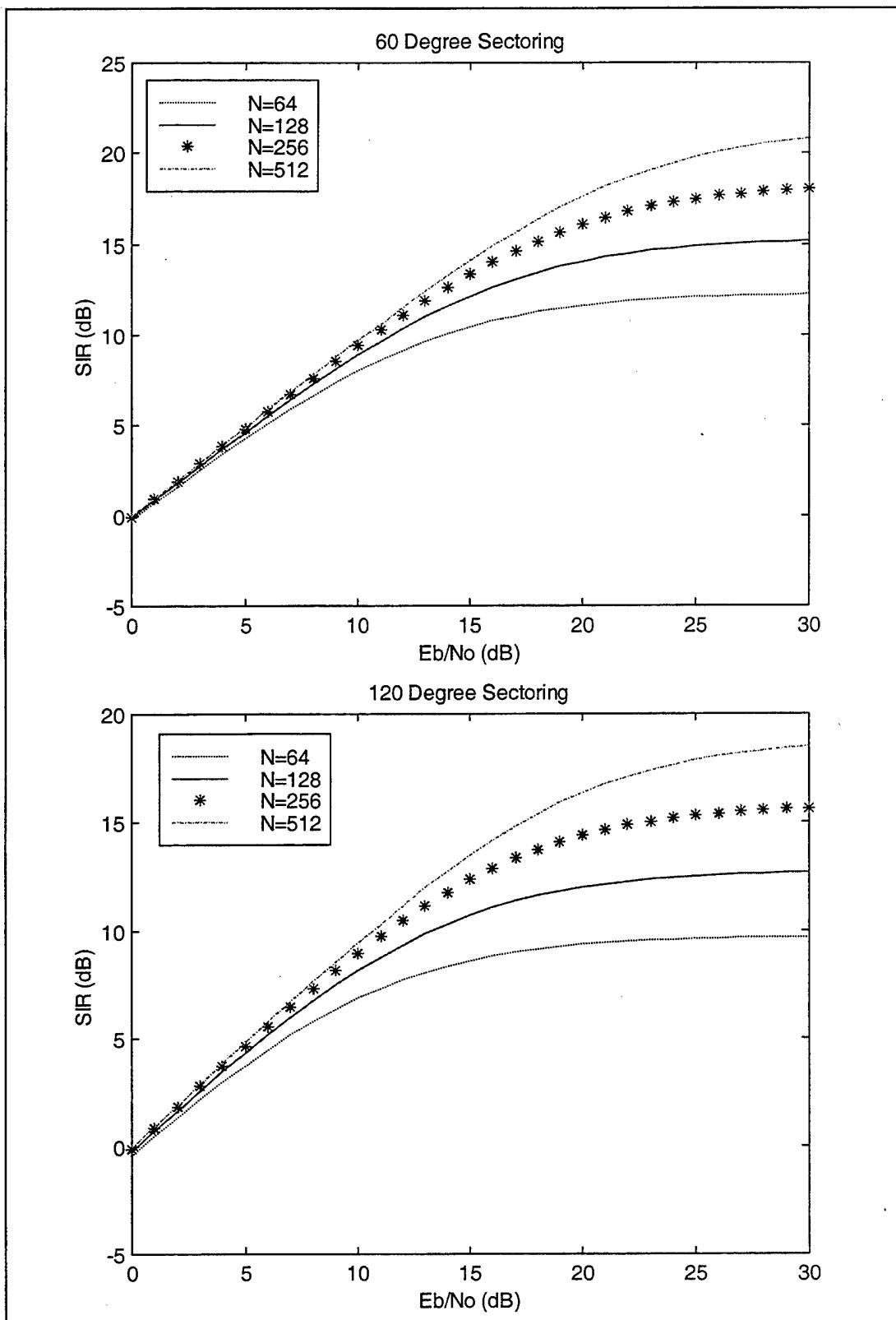
Figure 5.14: The Performance of the CDMA System Employing Sectoring with Overlap Angle of 10, K=56, n=4, and α =0.4.
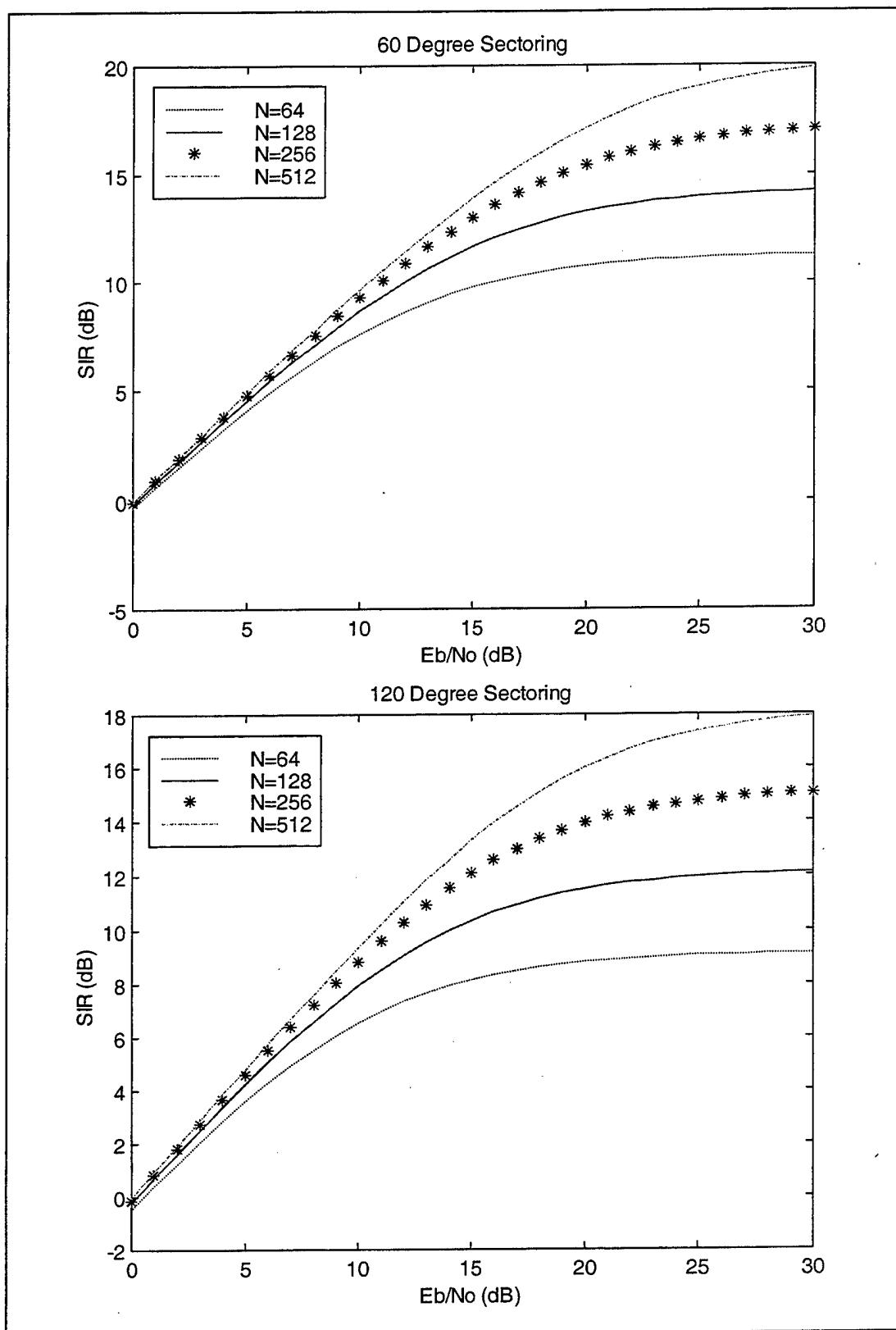
Figure 5.15: The Performance of the CDMA System Employing Sectoring with Overlap Angle of 20, K=56, n=4, and α =0.4.
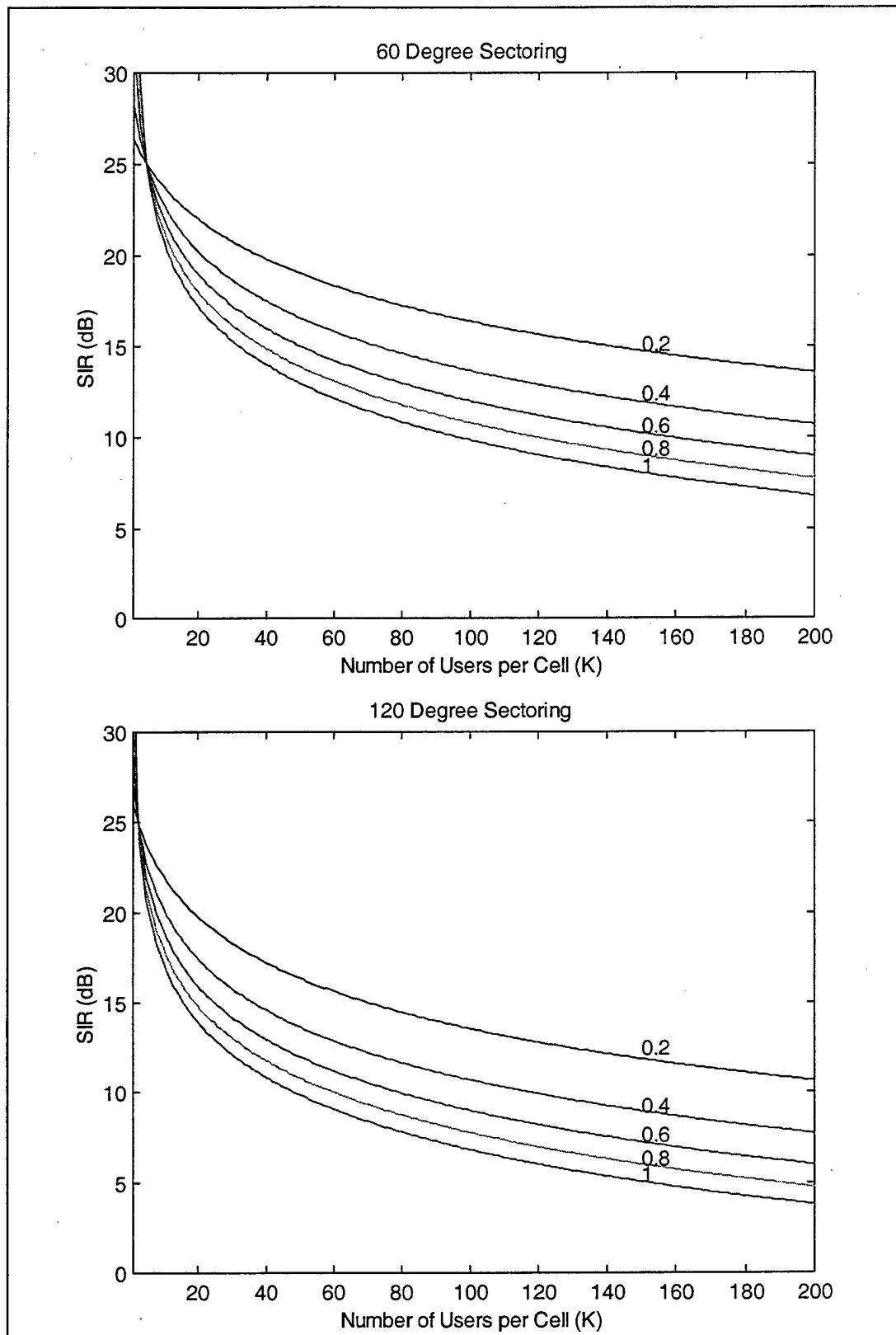
Figure 5.16: The System Capacity of the CDMA Employing Sectoring with Overlap Angle of 0 (Perfect Sectoring), N=128, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
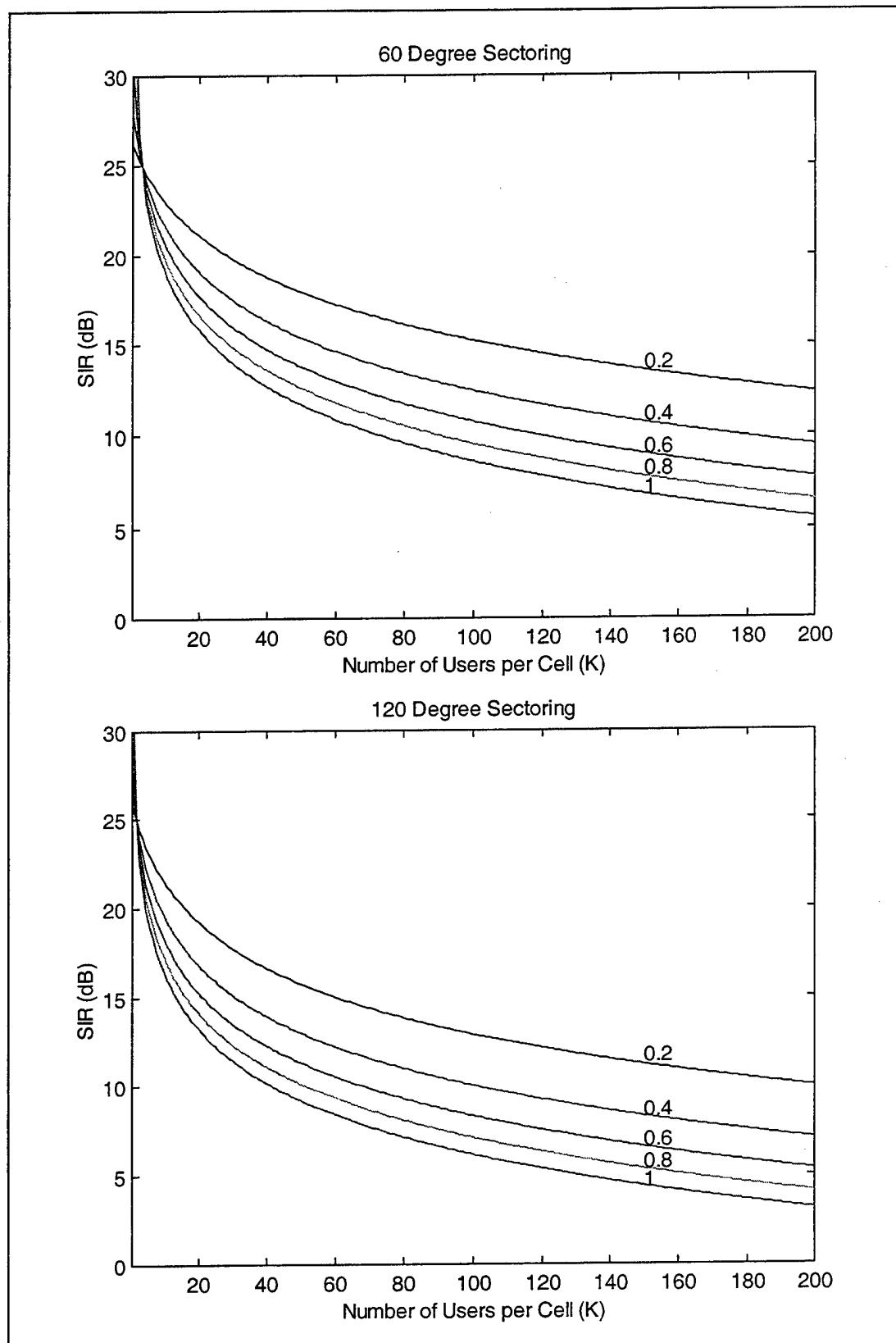
Figure 5.17: The System Capacity of the CDMA Employing Sectoring with Overlap Angle of 10, N=128, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
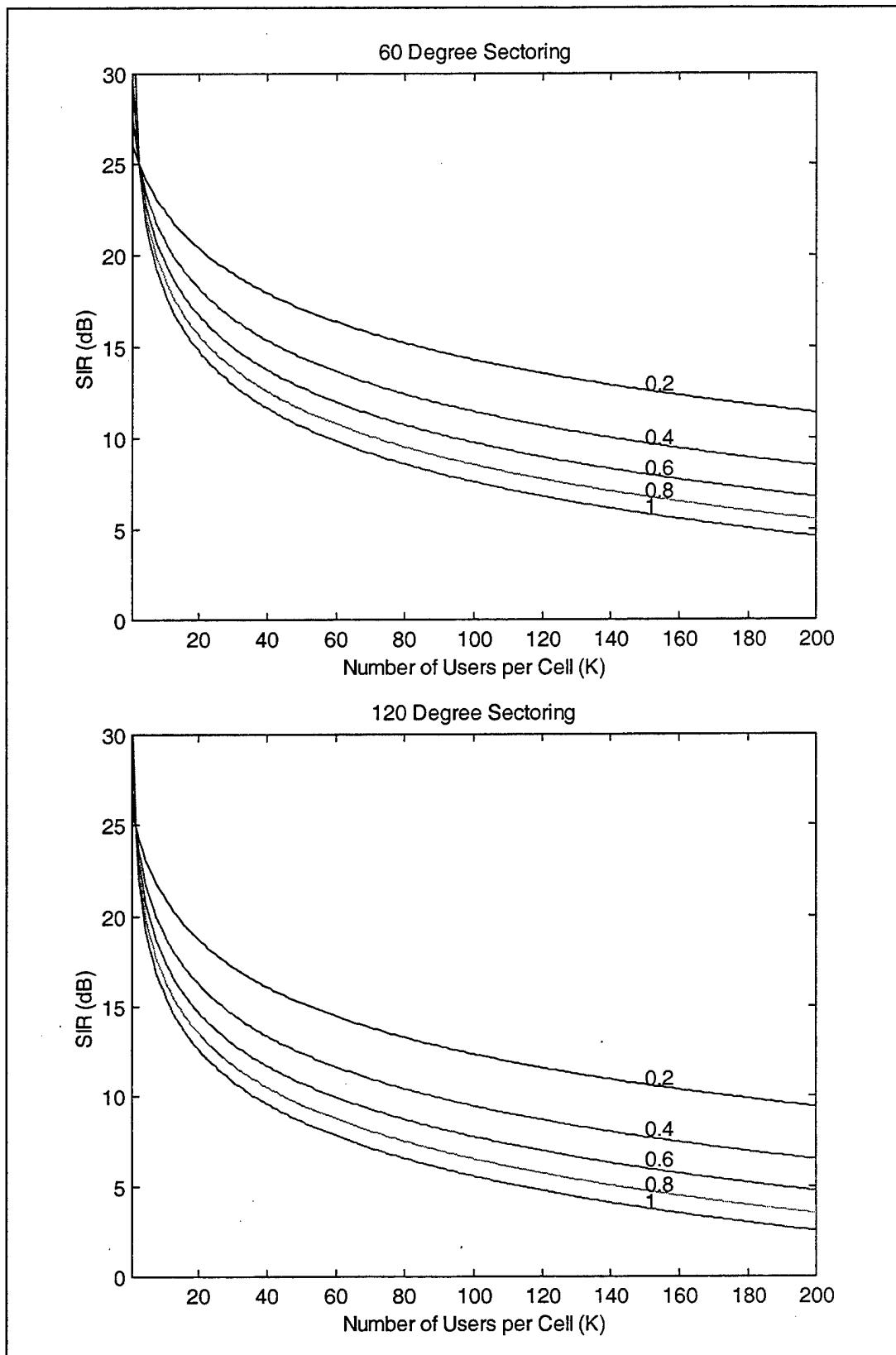
Figure 5.18: The System Capacity of the CDMA Employing Sectoring with Overlap Angle of 20, N=128, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
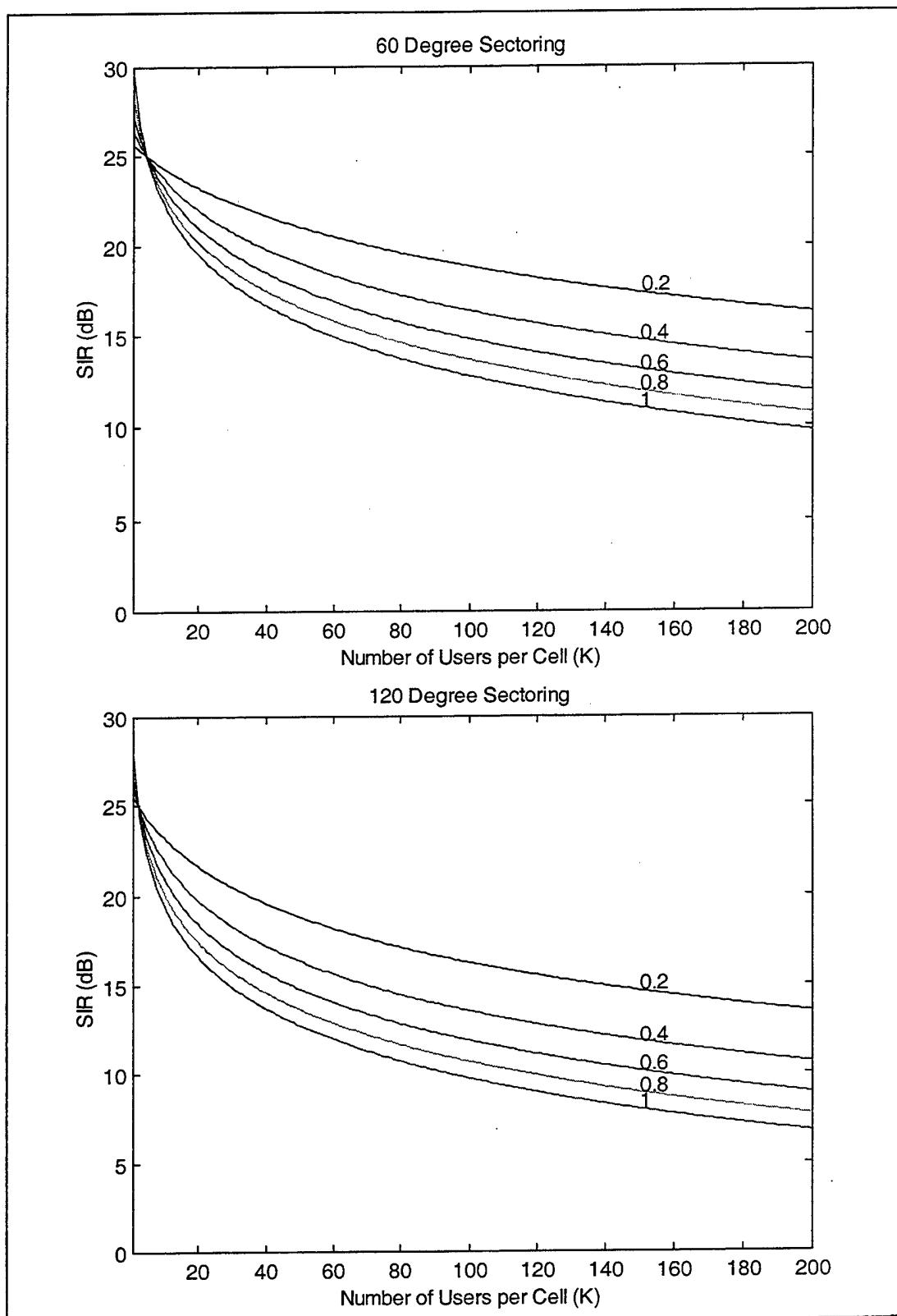
Figure 5.19: The System Capacity of the CDMA Employing Sectoring with Overlap Angle of 0 (Perfect Sectoring), N=256, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
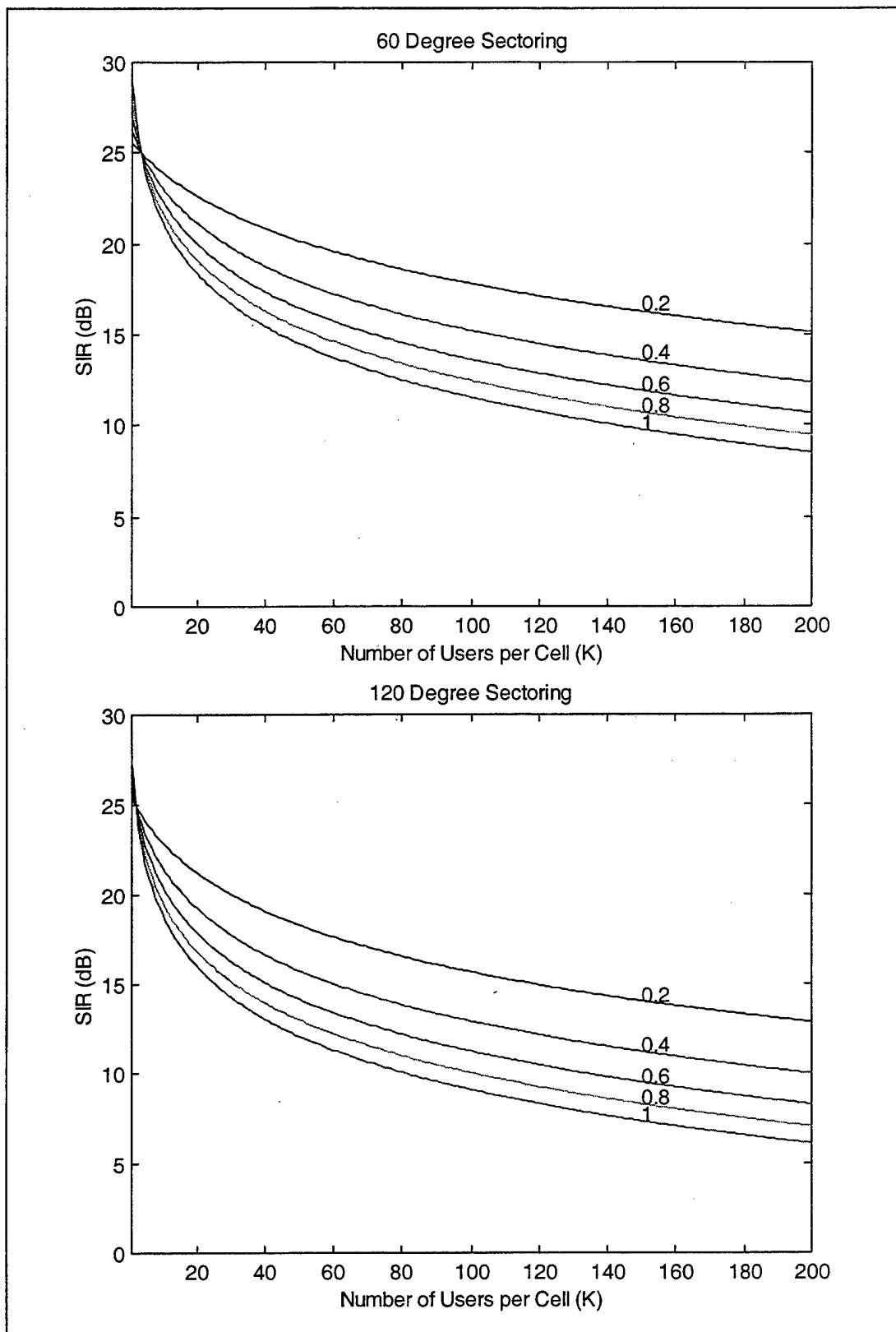
Figure 5.20: The System Capacity of the CDMA Employing Sectoring with Overlap
Angle of 10, N=256, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
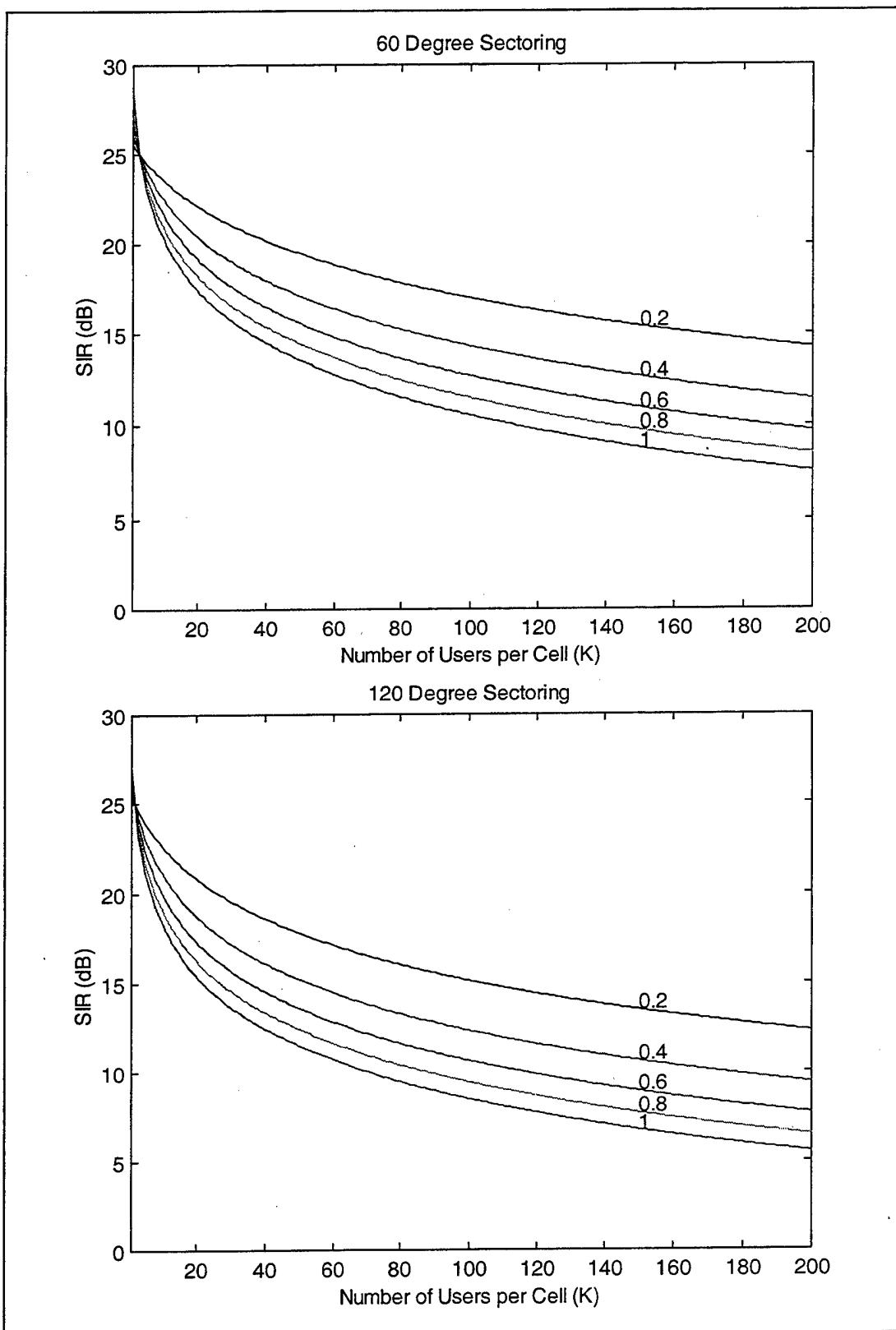
Figure 5.21: The System Capacity of the CDMA Employing Sectoring with Overlap Angle of 20, N=256, Eb/No=25 dB, n=4, and α =0.2, 0.4, 0.6, 0.8, 1.
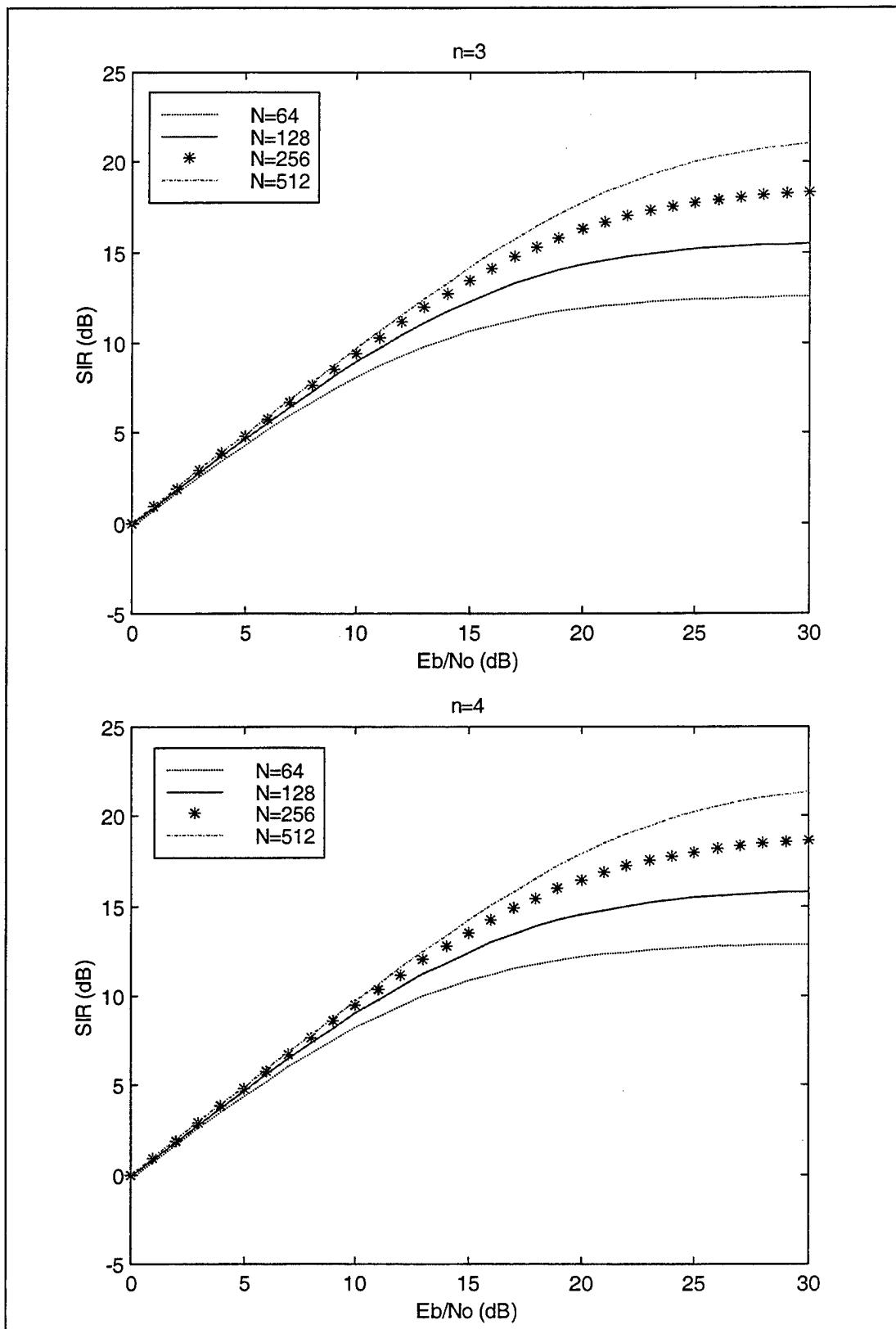
Figure 5.22: The Performance of the CDMA System Employing Microzoning Concept with K=24 (8 users per zone), and α =0.2.
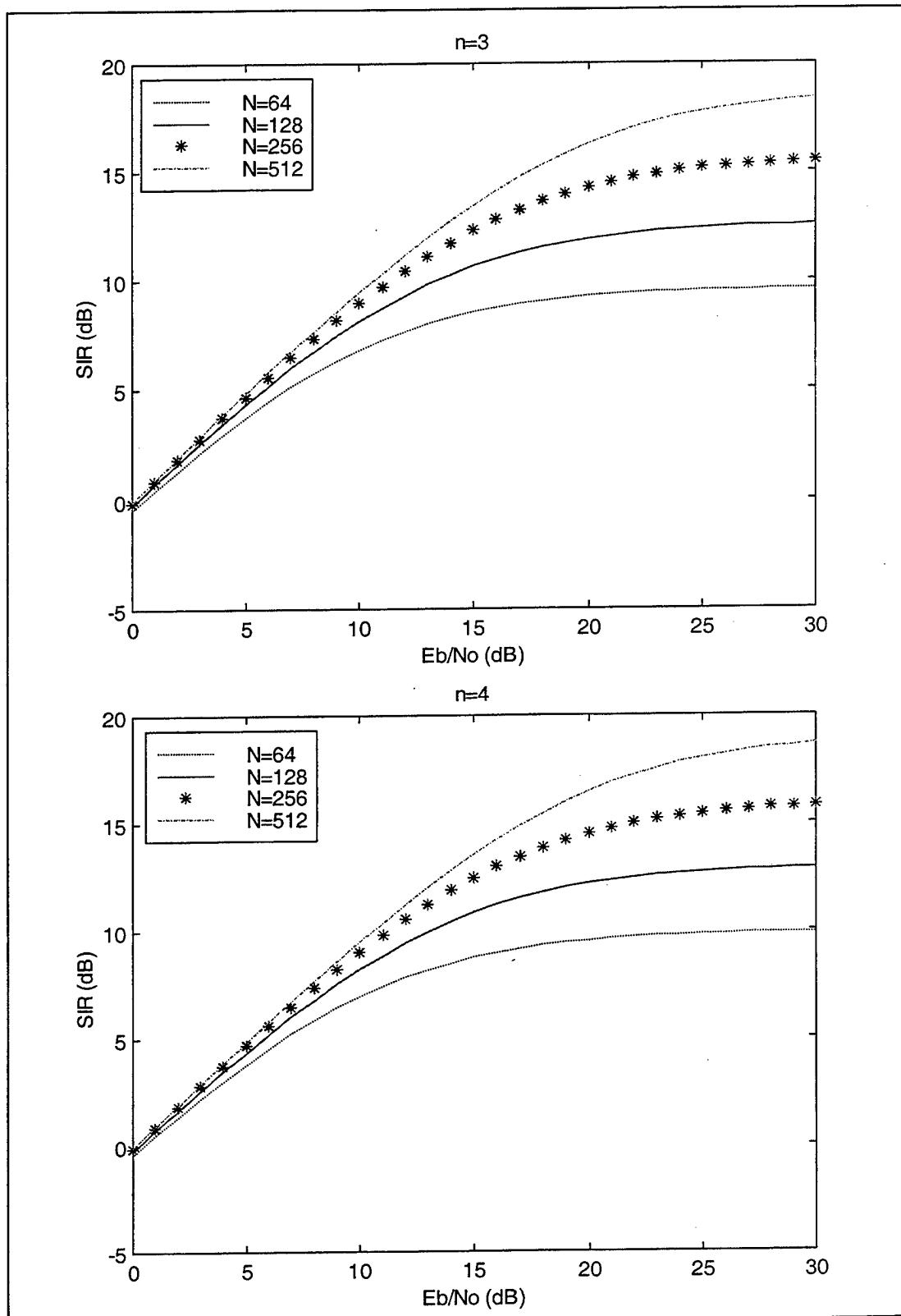
Figure 5.23: The Performance of the CDMA System Employing Microzoning Concept with K=24 (8 users per zone), and α =0.4.
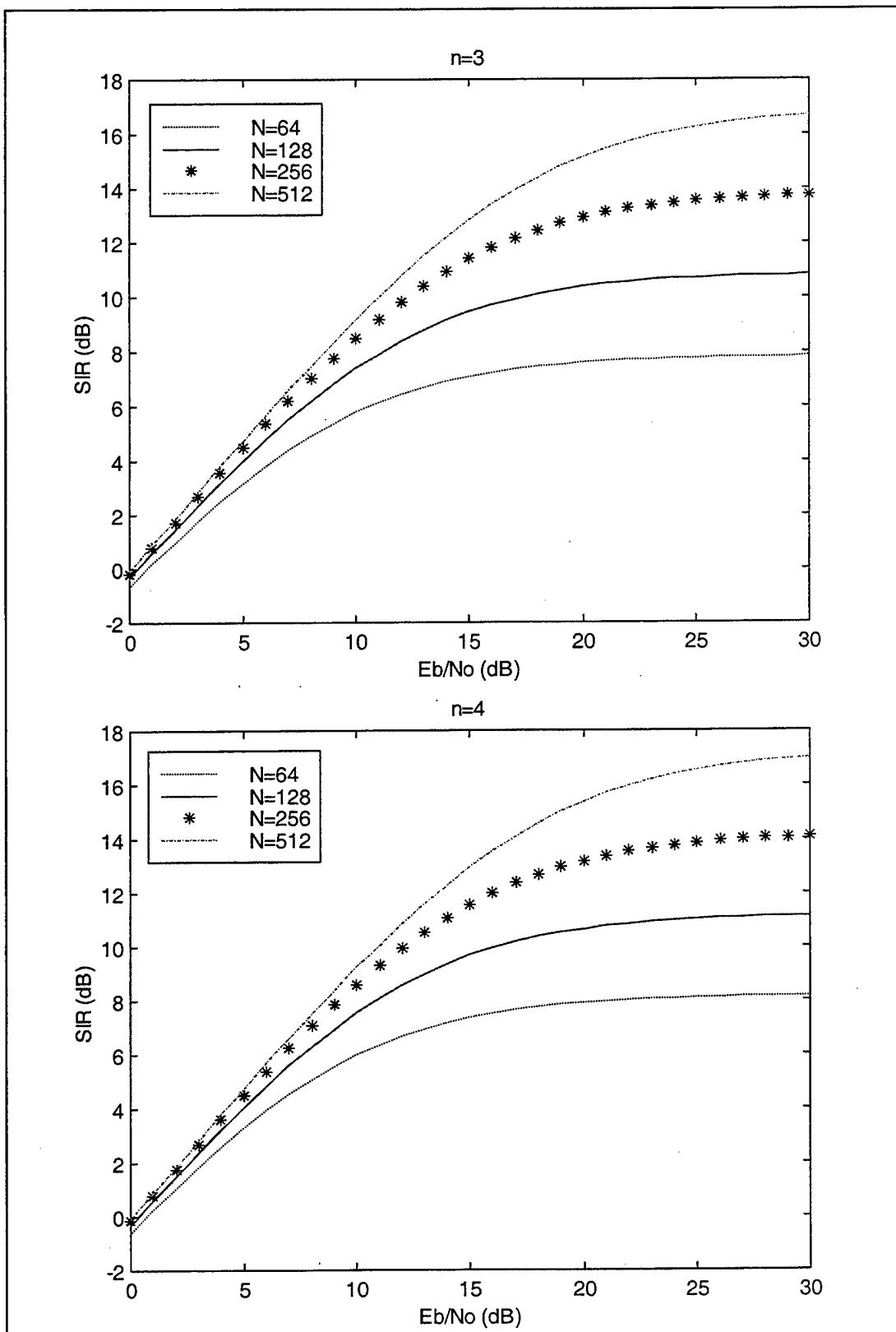
Figure 5.24: The Performance of the CDMA System Employing Microzoning Concept with K=24 (8 users per zone), and α =0.6.
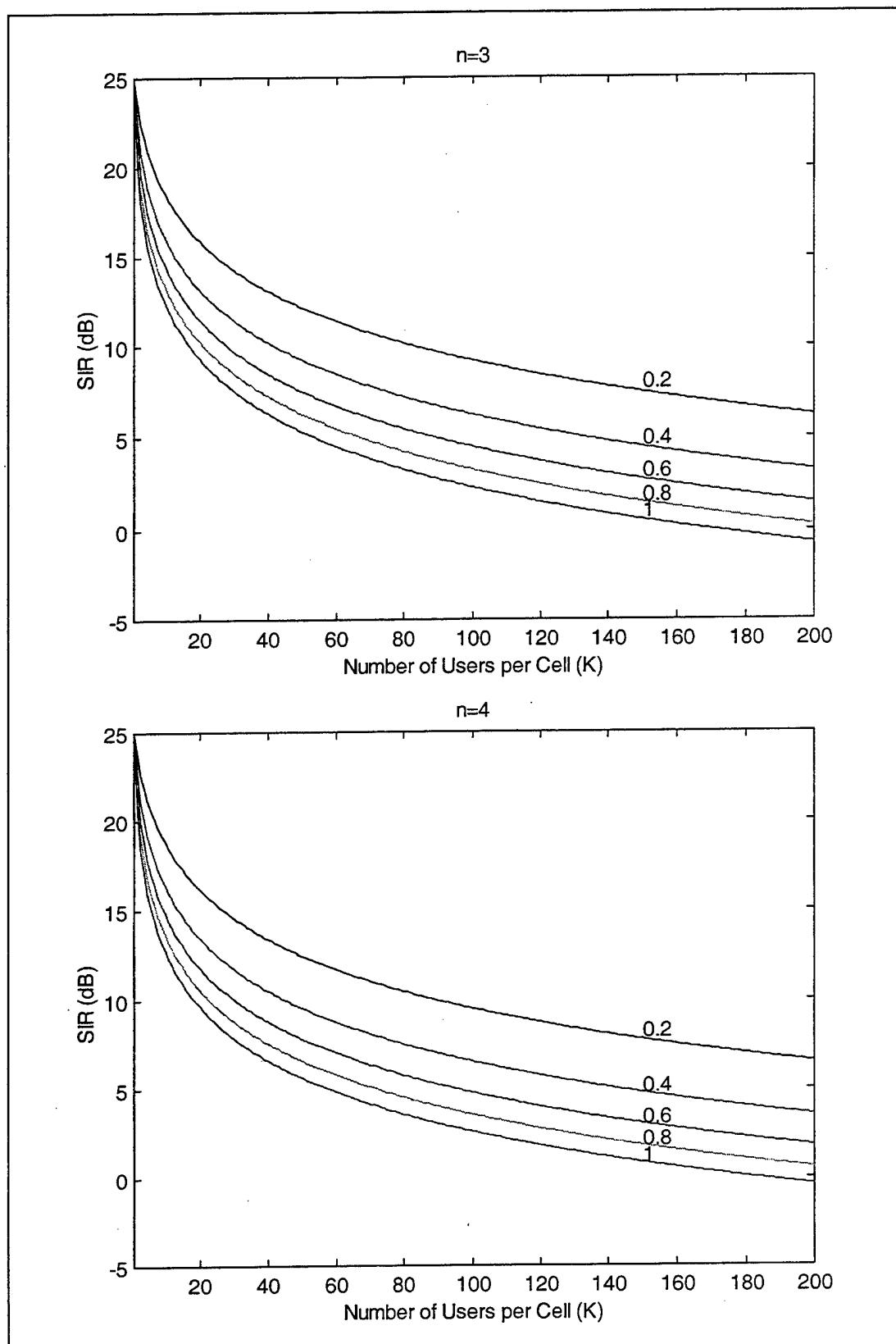
Figure 5.25: The System Capacity of the CDMA Employing Microzoning Concept with Spreading Factor of 128, Eb/No=25 dB, and α =0.2, 0.4, 0.6, 0.8, 1.
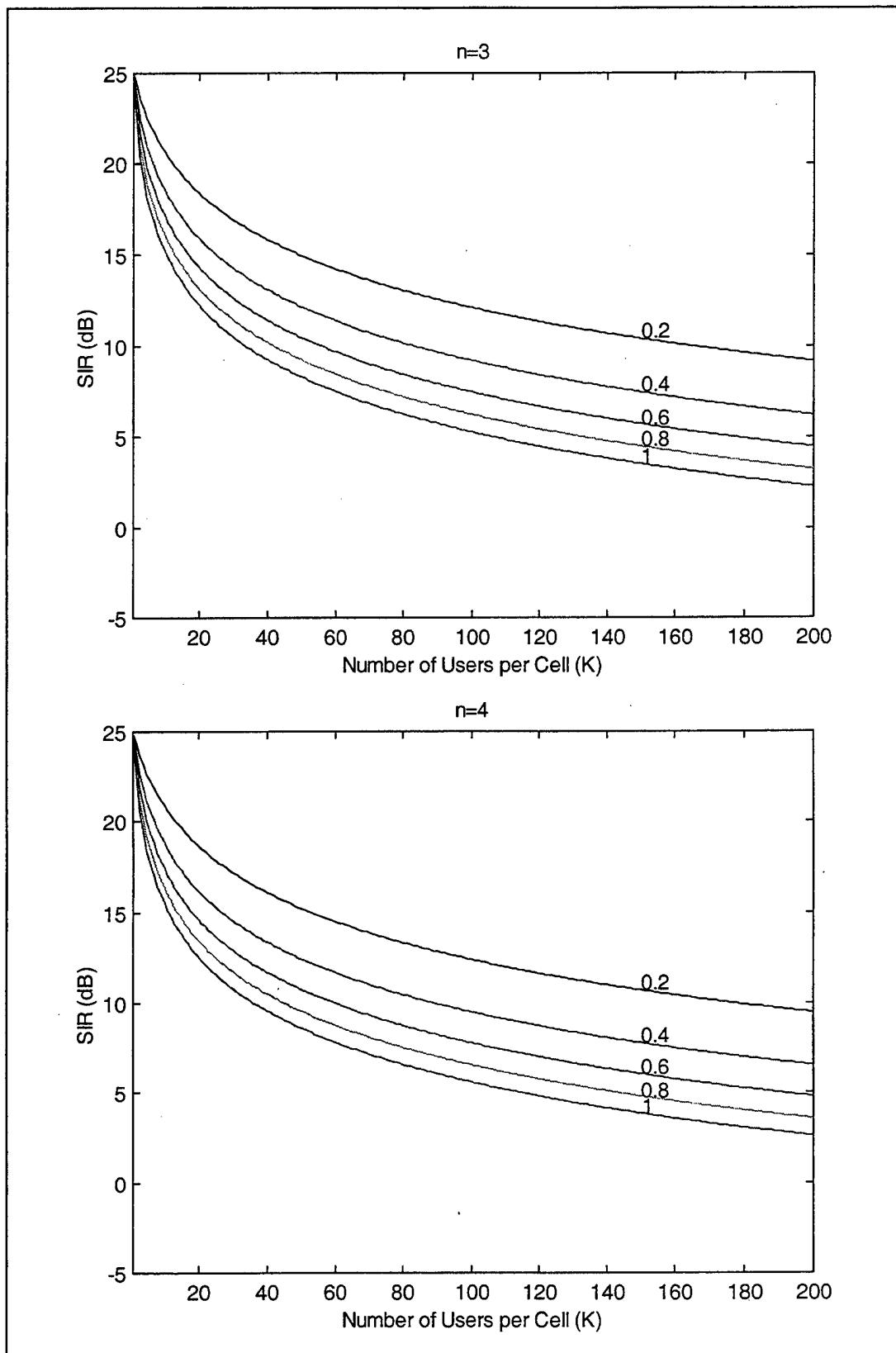
Figure 5.26: The System Capacity of the CDMA Employing Microzoning Concept with Spreading Factor of 256, Eb/No=25 dB, and α =0.2, 0.4, 0.6, 0.8, 1.
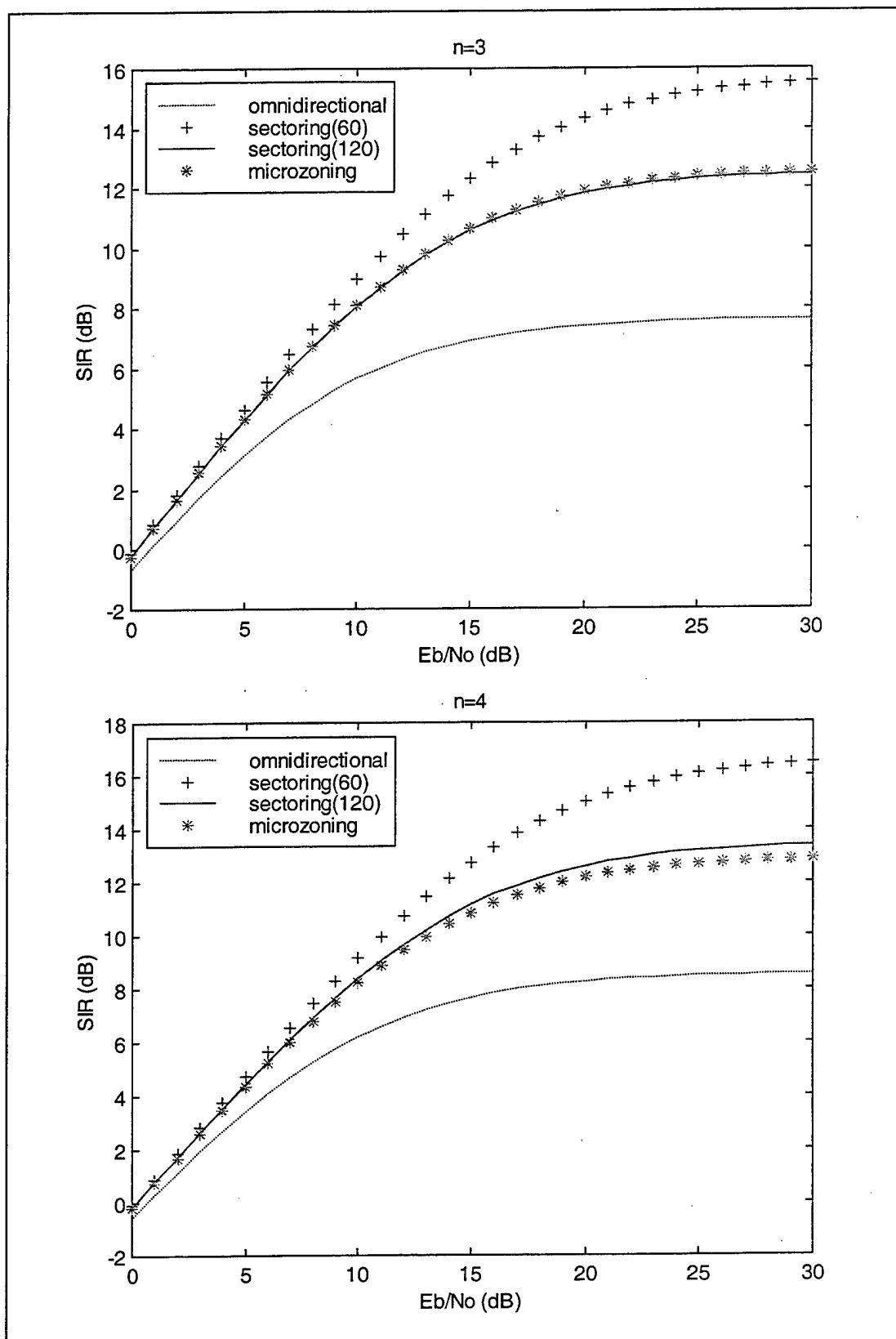
Figure 5.27: Performance Comparison of CDMA System with Overlap Angle of 0 (Perfect Sectoring), N=128, α =0.4, and K=56 (8 users per small hexagon/zone).
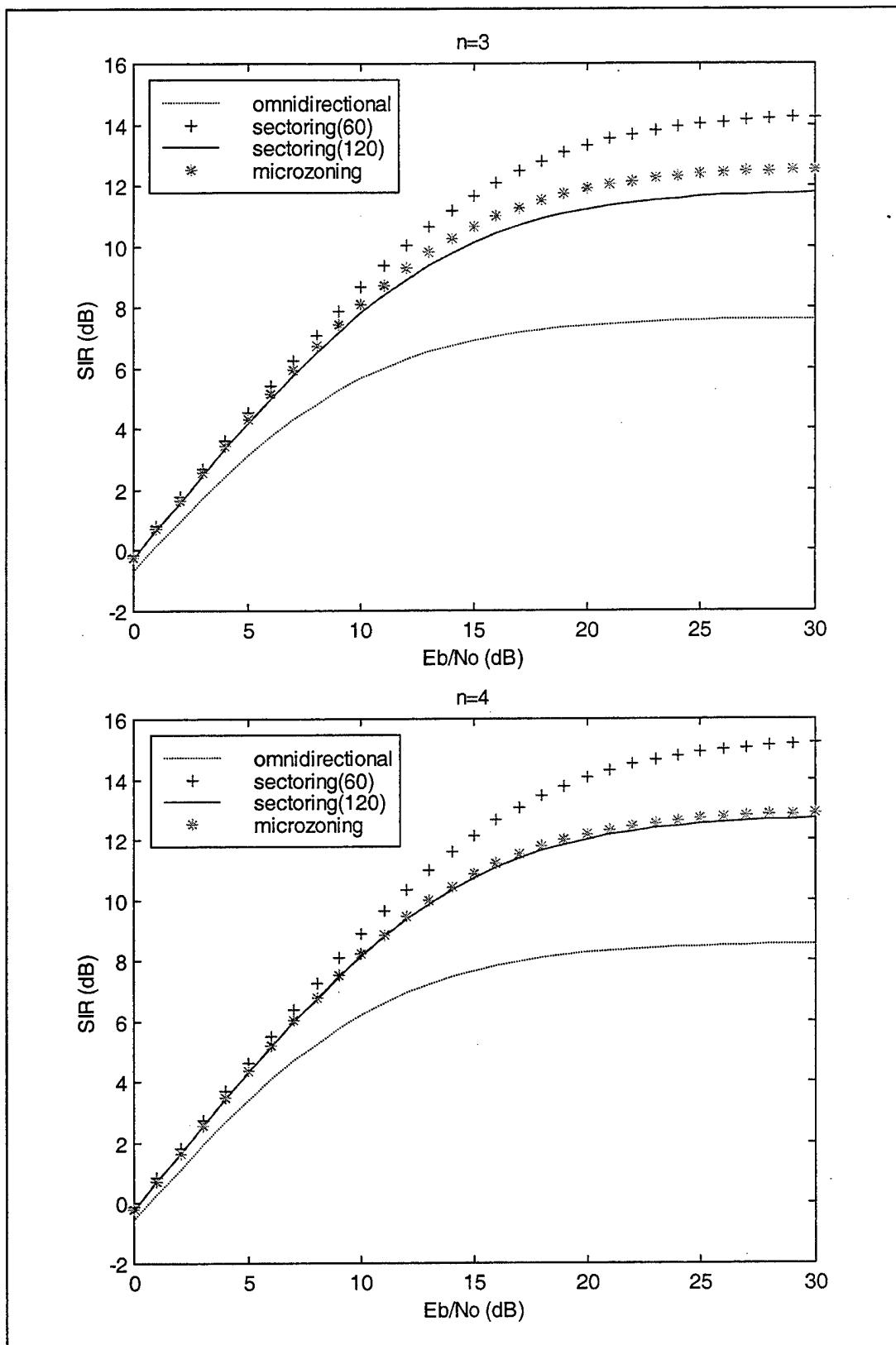
Figure 5.28: Performance Comparison of CDMA System with Overlap Angle of 10, N=128, α =0.4, and K=56 (8 users per small hexagon/zone).
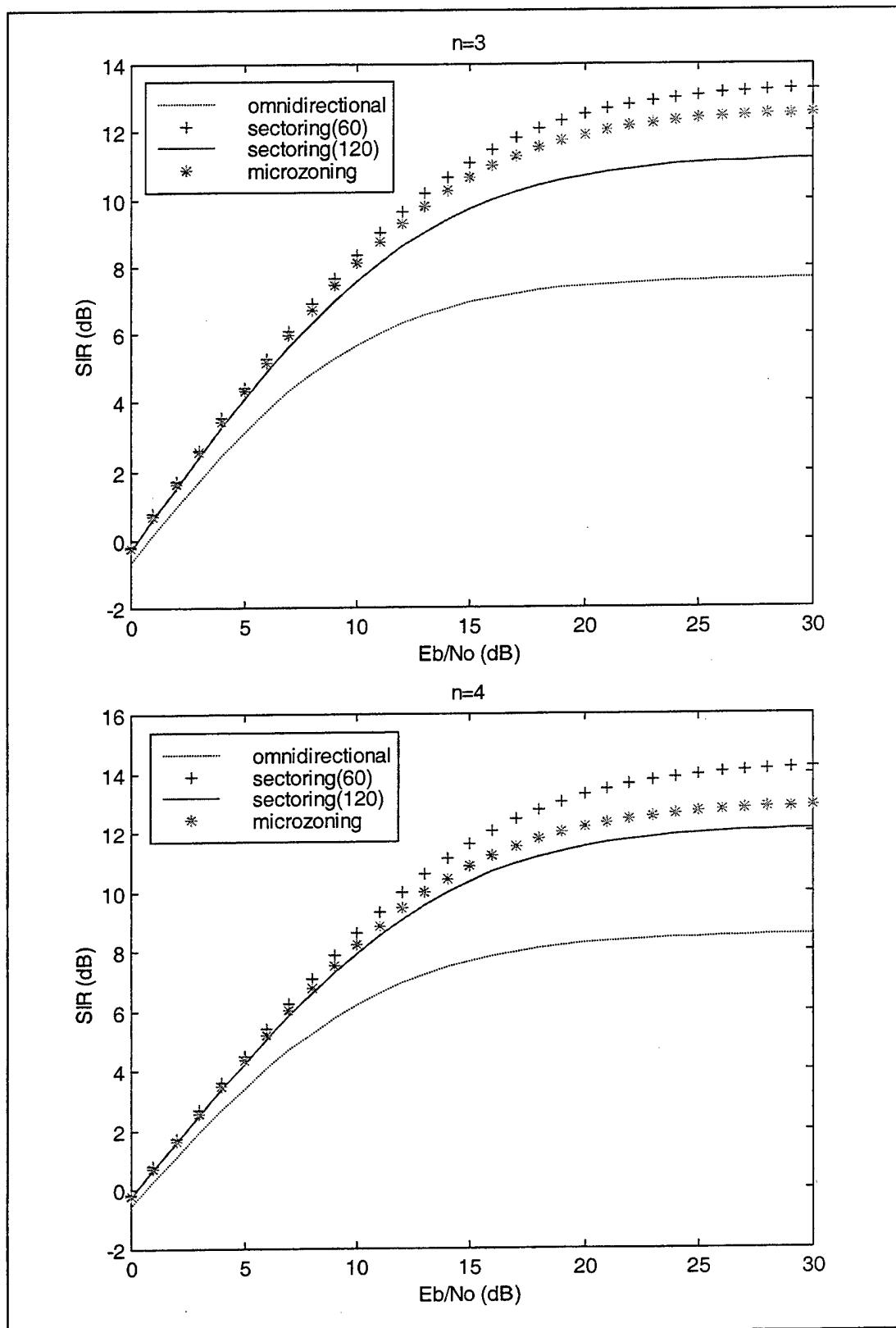
Figure 5.29: Performance Comparison of CDMA System with Overlap Angle of 20, N=128, α =0.4, and K=56 (8 users per small hexagon/zone).
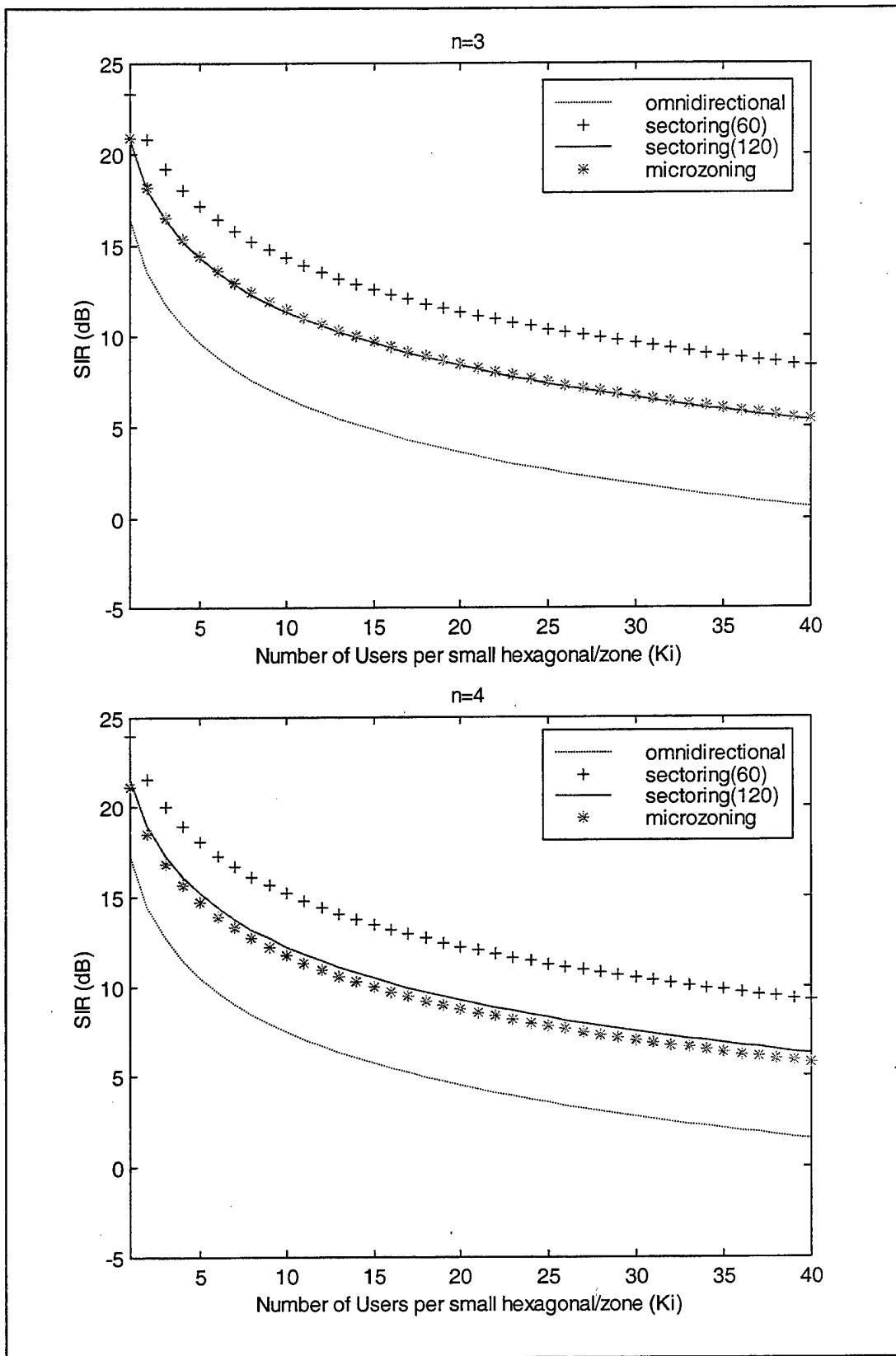
Figure 5.30: Capacity Comparison of CDMA System with Overlap Angle of 0 (Perfect Sectoring), N=128, α =0.4, and Eb/No=25 dB.
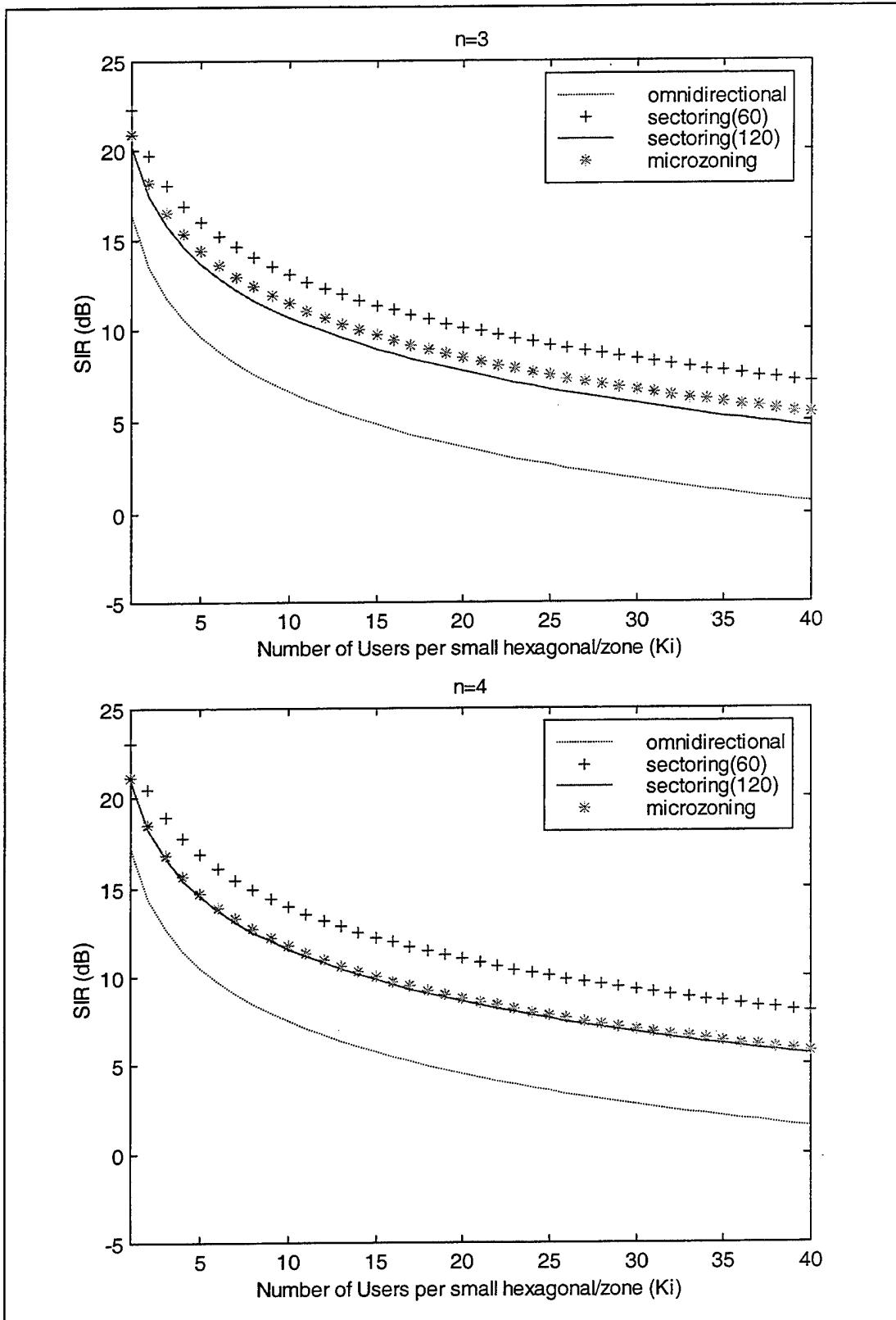
Figure 5.31: Capacity Comparison of CDMA System with Overlap Angle of 10, N=128, α =0.4, and Eb/No=25 dB.
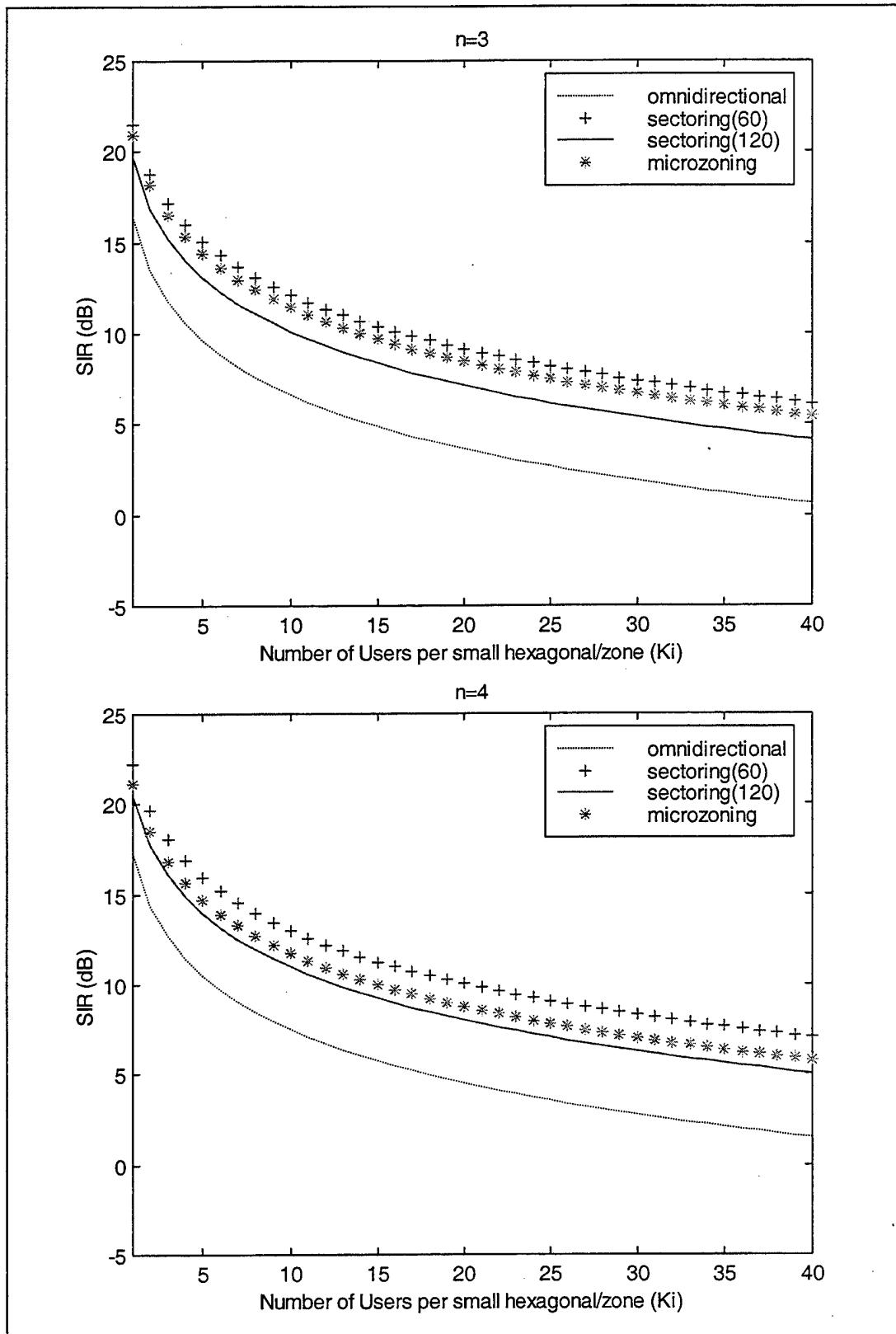
Figure 5.32: Capacity Comparison of CDMA System with Overlap Angle of 20, N=128, α =0.4, and Eb/No=25 dB.

VI.   CONCLUSION

The current mobile communication systems are narrowband and optimized for voice. They can not support high data rate applications. In order to support the explosive growth rate of multimedia mobile communications, new technologies must be developed to provide reliable, high data rate services. Of the multiple access techniques used in cellular communications, it appears that CDMA is the strongest candidate for the third generation mobile communication systems.

The primary restriction on performance in CDMA is the co-channel interference. Since CDMA capacity is interference limited, the interference reduction equates to better quality of service and greater user capacity.

In this thesis, several interference reduction methods including microzoning concept which was presented for the narrowband systems in the past, have been analyzed on the reverse link of CDMA cellular systems operating with perfect power control. Although a simple propagation model was assumed in the calculation of signal to interference ratio values, the model is reasonable for the cellular systems in flat service areas. The multiuser interference is modeled analytically for an environment with typical path loss exponents.

As a common spatial interference reduction method, the capacity of sectoring system of a CDMA was studied in Chapter III. Although 60^0 sectoring has better performance than the microzoning system in the simulation results, in a microzoning system, since fewer soft/softer handoffs are needed as compared to the sectoring system, both the switching load and the control link load are cut roughly by half as projected in Chapter IV. Imperfect sectoring and nonhomogenous user density such as along a

seacoast bordered by a mountain range causes sectoring problems. On the other hand, the need of multiple zone stations for each cell, and the connection of these zone stations to the base station, the microzoning system needs more infrastructure and hardware.

When we solve these technical problems for each method, microzoning and 60^0 sectoring seem very promising candidates for providing the necessary interference reduction to enable the operation of the third generation high data rate cellular systems.

Currently, there are other investigations on how to reduce the interference and increase the capacity of CDMA systems. One of them is "adaptive antenna" which provides individual spot beams for each user in the cell. Another is the "interference cancellation" scheme which operates on the fact that the base station receiving all communications within the cell can cancel out individual mobile transmissions since it knows their PN codes. Additional investigations deal with optimum pulse shapes [Ref. 10] to increase the correlation between the intended signal and its PN code.

In the future, comparisons between the various methods mentioned above and sectoring and microzoning could be carried out. Combinations of these reduction methods can decrease the interference and thus increase the capacity of CDMA systems.

APPENDIX

CALCULATION OF THE LOCATIONS AND THE DISTANCES OF THE FIRST AND SECOND TIER CO-CHANNEL CELLS

In this appendix, the location of each mobile station in the first and second tier co-channel cells is found and its distance to reference base station calculated. To simplify the calculation of the distances between the reference base station and the interfering mobile stations in the co-channel cells, lets locate the reference base station at the center of a x-y coordinate system as shown in Figure App-1.
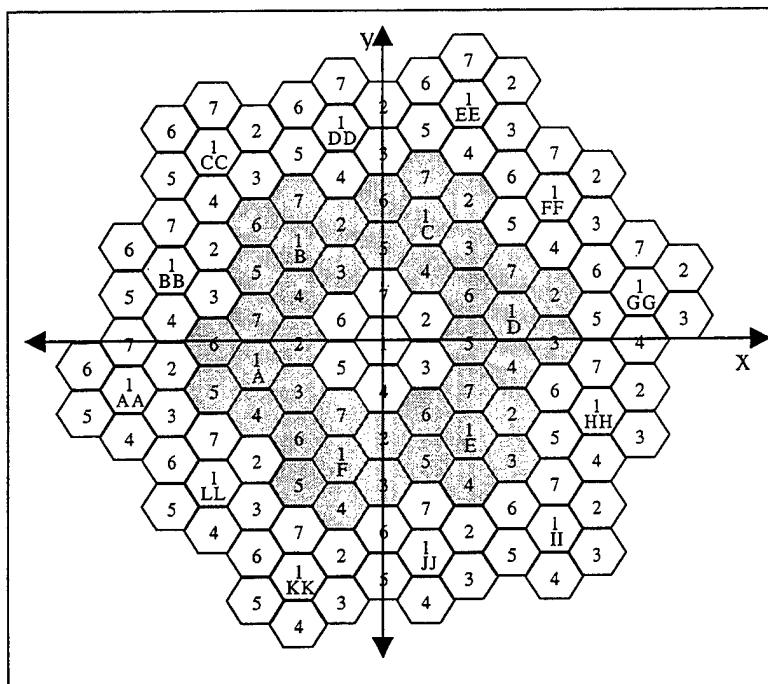
Figure App-1: The location of the first and second tier co-channel cells on the x-y coordinate system

Using the Figure above we can obtain the coordinates of each mobile station which is located at the center of the "small hexagonal cells" except the first small hexagonal cell in each cell. As we mentioned in Chapter II, we assumed that the center mobile station in each co-channel cell is located R/2 units from its base station, in the direction of the reference base station to manage the "0 distance" phenomena. Thus, the locations of the mobile stations in the first tier co-channel cells are:

$$A_1 = \left(-\frac{9}{2}, -\frac{\sqrt{3}}{2}\right), A_2 = (-3,0), A_3 = \left(-3, -\sqrt{3}\right), A_4 = \left(-\frac{9}{2}, -\frac{3\sqrt{3}}{2}\right), A_5 = \left(-6, -\sqrt{3}\right), A_6(-6,0), A_7 = \left(-\frac{9}{2}, \frac{\sqrt{3}}{2}\right)$$

$$B_1 = \left(-3, 2\sqrt{3}\right), B_2 = \left(-\frac{3}{2}, \frac{5\sqrt{3}}{2}\right), B_3 = \left(-\frac{3}{2}, \frac{3\sqrt{3}}{2}\right), B_4 = \left(-3, \sqrt{3}\right), B_5 = \left(-\frac{9}{2}, \frac{3\sqrt{3}}{2}\right), B_6 = \left(-\frac{9}{2}, \frac{5\sqrt{3}}{2}\right), B_7 = \left(-3, 3\sqrt{3}\right)$$

$$C_1 = \left(\frac{3}{2}, \frac{5\sqrt{3}}{2}\right), C_2 = \left(3, 3\sqrt{3}\right), C_3 = \left(3, 2\sqrt{3}\right), C_4 = \left(\frac{3}{2}, \frac{3\sqrt{3}}{2}\right), C_5 = \left(0, 2\sqrt{3}\right), C_6 = \left(0, 3\sqrt{3}\right), C_7 = \left(\frac{3}{2}, \frac{7\sqrt{3}}{2}\right)$$

$$D_1 = \left(\frac{9}{2}, \frac{\sqrt{3}}{2}\right), D_2 = \left(6, \sqrt{3}\right), D_3 = (6,0), D_4 = \left(\frac{9}{2}, -\frac{\sqrt{3}}{2}\right), D_5 = (3,0), D_6 = \left(3, \sqrt{3}\right), D_7 = \left(\frac{9}{2}, \frac{3\sqrt{3}}{2}\right)$$

$$E_1 = \left(3, -2\sqrt{3}\right), E_2 = \left(\frac{9}{2}, -\frac{3\sqrt{3}}{2}\right), E_3 = \left(\frac{9}{2}, \frac{-5\sqrt{3}}{2}\right), E_4 = \left(3, -3\sqrt{3}\right), E_5 = \left(\frac{3}{2}, -\frac{5\sqrt{3}}{2}\right), E_6 = \left(\frac{3}{2}, -\frac{3\sqrt{3}}{2}\right), E_7 = \left(3, -\sqrt{3}\right)$$

$$F_1 = \left(-\frac{3}{2}, -\frac{5\sqrt{3}}{2}\right), F_2 = \left(0, -2\sqrt{3}\right), F_3 = \left(0, -3\sqrt{3}\right), F_4 = \left(-\frac{3}{2}, -\frac{7\sqrt{3}}{2}\right), F_5 = \left(-3, -3\sqrt{3}\right), F_6 = \left(-3, -2\sqrt{3}\right), F_7 = \left(-\frac{3}{2}, -\frac{3\sqrt{3}}{2}\right)$$

And, the locations of the mobile stations in the second tier co-channel cells are:

$$AA_1 = \left(-9, -\sqrt{3}\right), AA_2 = \left(-\frac{15}{2}, -\frac{\sqrt{3}}{2}\right), AA_3 = \left(-\frac{15}{2}, -\frac{3\sqrt{3}}{2}\right), AA_4 = \left(-9, -2\sqrt{3}\right), AA_5 = \left(-\frac{21}{2}, -\frac{3\sqrt{3}}{2}\right), AA_6 = \left(-\frac{21}{2}, -\frac{\sqrt{3}}{2}\right), AA_7 = (-9,0)$$

$$BB_1 = \left(-\frac{15}{2}, \frac{3\sqrt{3}}{2}\right), BB_2 = \left(-6, 2\sqrt{3}\right), BB_3 = \left(-6, \sqrt{3}\right), BB_4 = \left(-\frac{15}{2}, \frac{\sqrt{3}}{2}\right), BB_5 = \left(-9, \sqrt{3}\right), BB_6 = \left(-9, 2\sqrt{3}\right), BB_7 = \left(-\frac{15}{2}, \frac{5\sqrt{3}}{2}\right)$$

$$CC_1 = \left(-6, 4\sqrt{3}\right), CC_2 = \left(-\frac{9}{2}, \frac{9\sqrt{3}}{2}\right), CC_3 = \left(-\frac{9}{2}, \frac{7\sqrt{3}}{2}\right), CC_4 = \left(-6, 3\sqrt{3}\right), CC_5 = \left(-\frac{15}{2}, \frac{7\sqrt{3}}{2}\right), CC_6 = \left(-\frac{15}{2}, \frac{9\sqrt{3}}{2}\right), CC_7 = \left(-6, 5\sqrt{3}\right)$$

$$DD_1 = \left(-\frac{3}{2}, \frac{9\sqrt{3}}{2}\right), DD_2 = \left(0, 5\sqrt{3}\right), DD_3 = \left(0, 4\sqrt{3}\right), DD_4 = \left(-\frac{3}{2}, \frac{7\sqrt{3}}{2}\right), DD_5 = \left(-3, 4\sqrt{3}\right), DD_6 = \left(-3, 5\sqrt{3}\right), DD_7 = \left(-\frac{3}{2}, \frac{11\sqrt{3}}{2}\right)$$

$$EE_1 = \left(3, 5\sqrt{3}\right), EE_2 = \left(\frac{9}{2}, \frac{11\sqrt{3}}{2}\right), EE_3 = \left(\frac{9}{2}, \frac{9\sqrt{3}}{2}\right), EE_4 = \left(3, 4\sqrt{3}\right), EE_5 = \left(\frac{3}{2}, \frac{9\sqrt{3}}{2}\right), EE_6 = \left(\frac{3}{2}, \frac{11\sqrt{3}}{2}\right), EE_7 = \left(3, 6\sqrt{3}\right)$$

$$FF_1 = \left(6, 3\sqrt{3}\right), FF_2 = \left(\frac{15}{2}, \frac{7\sqrt{3}}{2}\right), FF_3 = \left(\frac{15}{2}, \frac{5\sqrt{3}}{2}\right), FF_4 = \left(6, 2\sqrt{3}\right), FF_5 = \left(\frac{9}{2}, \frac{5\sqrt{3}}{2}\right), FF_6 = \left(\frac{9}{2}, \frac{7\sqrt{3}}{2}\right), FF_7 = \left(6, 4\sqrt{3}\right)$$

$$GG_1 = \left(9, \sqrt{3}\right), GG_2 = \left(\frac{21}{2}, \frac{3\sqrt{3}}{2}\right), GG_3 = \left(\frac{21}{2}, \frac{\sqrt{3}}{2}\right), GG_4 = (9,0), GG_5 = \left(\frac{15}{2}, \frac{\sqrt{3}}{2}\right), GG_6 = \left(\frac{15}{2}, \frac{3\sqrt{3}}{2}\right), GG_7 = \left(9, 2\sqrt{3}\right)$$

$$HH_1 = \left(\frac{15}{2}, -\frac{3\sqrt{3}}{2}\right), HH_2 = \left(9, -\sqrt{3}\right), HH_3 = \left(9, -2\sqrt{3}\right), HH_4 = \left(\frac{15}{2}, -\frac{5\sqrt{3}}{2}\right), HH_5 = \left(6, -2\sqrt{3}\right), HH_6 = \left(6, -\sqrt{3}\right), HH_7 = \left(\frac{15}{2}, -\frac{\sqrt{3}}{2}\right)$$

$$II_1 = \left(6, -4\sqrt{3}\right), II_2 = \left(\frac{15}{2}, -\frac{7\sqrt{3}}{2}\right), II_3 = \left(\frac{15}{2}, -\frac{9\sqrt{3}}{2}\right), II_4 = \left(6, -5\sqrt{3}\right), II_5 = \left(\frac{9}{2}, -\frac{9\sqrt{3}}{2}\right), II_6 = \left(\frac{9}{2}, -\frac{7\sqrt{3}}{2}\right), II_7 = \left(6, -3\sqrt{3}\right)$$

$$JJ_1 = \left(\frac{3}{2}, -\frac{9\sqrt{3}}{2}\right), JJ_2 = \left(3, -4\sqrt{3}\right), JJ_3 = \left(3, -5\sqrt{3}\right), JJ_4 = \left(\frac{3}{2}, -\frac{11\sqrt{3}}{2}\right), JJ_5 = \left(0, -5\sqrt{3}\right), JJ_6 = \left(0, -4\sqrt{3}\right), JJ_7 = \left(\frac{3}{2}, -\frac{7\sqrt{3}}{2}\right)$$

$$KK_1 = \left(-3, -5\sqrt{3}\right), KK_2 = \left(-\frac{3}{2}, -\frac{9\sqrt{3}}{2}\right), KK_3 = \left(-\frac{3}{2}, -\frac{11\sqrt{3}}{2}\right), KK_4 = \left(-3, -6\sqrt{3}\right), KK_5 = \left(-\frac{9}{2}, -\frac{11\sqrt{3}}{2}\right), KK_6 = \left(-\frac{9}{2}, -\frac{9\sqrt{3}}{2}\right), KK_7 \left(-3, -4\sqrt{3}\right)$$

$$LL_1 = \left(-6, -3\sqrt{3}\right), LL_2 = \left(-\frac{9}{2}, -\frac{5\sqrt{3}}{2}\right), LL_3 = \left(-\frac{9}{2}, -\frac{7\sqrt{3}}{2}\right), LL_4 = \left(-6, -4\sqrt{3}\right), LL_5 = \left(-\frac{15}{2}, -\frac{7\sqrt{3}}{2}\right), LL_6 = \left(-\frac{15}{2}, -\frac{5\sqrt{3}}{2}\right), LL_7 = \left(-6, -2\sqrt{3}\right)$$

Now using (2.9) and the locations above, we can find the distances between the reference base station and the interfering mobile stations in terms of R in the first tier co-channel cells as

$d_{A1}= 4.0826$, $d_{A2}= 3$, $d_{A3}= 3.4641$, $d_{A4}= 5.1962$, $d_{A5}= 6.2450$, $d_{A6}= 6$, $d_{A7}= 4.5826$

$d_{B1}= 4.0826$, $d_{B2}= 4.5826$, $d_{B3}= 3$, $d_{B4}= 3.4641$, $d_{B5}= 5.1962$, $d_{B6}= 6.2450$, $d_{B7}= 6$

$d_{C1}= 4.0826$, $d_{C2}= 6$, $d_{C3}= 4.5826$, $d_{C4}= 3$, $d_{C5}= 3.4641$, $d_{C6}= 5.1962$, $d_{C7}= 6.2450$

$d_{D1}= 4.0826$, $d_{D2}= 6.2450$, $d_{D3}= 6$, $d_{D4}= 4.5826$, $d_{D5}= 3$, $d_{D6}= 3.4641$, $d_{D7}= 5.1962$

$d_{E1}= 4.0826$, $d_{E2}= 5.1962$, $d_{E3}= 6.2450$, $d_{E4}= 6$, $d_{E5}= 4.5826$, $d_{E6}= 3$, $d_{E7}= 3.4641$

$d_{F1}= 4.0826$, $d_{F2}= 3.4641$, $d_{F3}= 5.1962$, $d_{F4}= 6.2450$, $d_{F5}= 6$, $d_{F6}= 4.5826$, $d_{F7}= 3$.

and, the distances between the reference base station and the interfering mobile stations in terms of R in the second tier co-channel cells as

$d_{AA1}= 8.6652$, $d_{AA2}= 7.5498$, $d_{AA3}= 7.9373$, $d_{AA4}= 9.6437$, $d_{AA5}= 10.8167$, $d_{AA6}= 10.5357$, $d_{AA7}= 9$

$d_{BB1}=7.4373$, $d_{BB2}= 6.9282$, $d_{BB3}= 6.245$, $d_{BB4}= 7.5498$, $d_{BB5}= 9.1652$, $d_{BB6}= 9.6437$, $d_{BB7}= 8.6603$

$d_{CC1}= 8.6652$, $d_{CC2}= 9$, $d_{CC3}= 7.5498$, $d_{CC4}= 7.9373$, $d_{CC5}= 9.6437$, $d_{CC6}= 10.8167$, $d_{CC7}= 10.5357$

$d_{DD1}= 7.4373$, $d_{DD2}= 8.6603$, $d_{DD3}= 6.9282$, $d_{DD4}=6.2450$, $d_{DD5}=7.5498$, $d_{DD6}=9.1652$, $d_{DD7}=9.6437$

$d_{EE1}= 8.6652$, $d_{EE2}= 10.5357$, $d_{EE3}= 9$, $d_{EE4}= 7.5498$, $d_{EE5}= 7.9373$, $d_{EE6}= 9.6437$, $d_{EE7}= 10.8167$

$d_{FF1}= 7.4373$, $d_{FF2}= 9.6437$, $d_{FF3}= 8.6603$, $d_{FF4}= 6.9282$, $d_{FF5}= 6.2450$, $d_{FF6}= 7.5498$, $d_{FF7}= 9.1652$

$d_{GG1}= 8.6652$, $d_{GG2}= 10.8167$, $d_{GG3}= 10.5357$, $d_{GG4}= 9$, $d_{GG5}= 7.5498$, $d_{GG6}= 7.9373$, $d_{GG7}= 9.6437$

$d_{HH1}= 7.4373$, $d_{HH2}= 9.1652$, $d_{HH3}=9.6437$, $d_{HH4}= 8.6603$, $d_{HH5}=6.9282$, $d_{HH6}=6.2450$, $d_{HH7}=7.5498$

$d_{II1}= 8.6652$, $d_{II2}= 9.6437$, $d_{II3}= 10.8167$, $d_{II4}= 10.5357$, $d_{II5}= 9$, $d_{II6}= 7.5498$, $d_{II7}= 7.9373$

$d_{JJ1}= 7.4373$, $d_{JJ2}= 7.5498$, $d_{JJ3}= 9.1652$, $d_{JJ4}= 9.6437$, $d_{JJ5}= 8.6603$, $d_{JJ6}= 6.9282$, $d_{JJ7}= 6.2450$

$d_{KK1}= 8.6652$, $d_{KK2}= 7.9373$, $d_{KK3}= 9.6437$, $d_{KK4}= 10.8167$, $d_{KK5}= 10.5357$, $d_{KK6}= 9$, $d_{KK7}= 7.5498$

$d_{LL1}= 7.4373$, $d_{LL2}= 6.2450$, $d_{LL3}= 7.5498$, $d_{LL4}= 9.1652$, $d_{LL5}= 9.6437$, $d_{LL6}= 8.6603$, $d_{LL7}= 6.9282$

LIST OF REFERENCES

1. Prasad, R., and Ojanpera, T., "A Survey on CDMA: Evolution towards Wideband CDMA," *IEEE 5th International Symposium on Communications*, Vol.1, 1998.

2. Dinan, E., Jabbari, B., "Spreading Codes for Direct sequence CDMA and Wideband CDMA and Wideband CDMA Cellular Networks," *IEEE Communications Magazine*, September 1998.

3. Glisic, S., and Vucetic, B., *Spread Spectrum CDMA Systems for Wireless Communications*, Arctech House, Norwood, MA, 1997.

4. Motorola Homepage, *CDMA Technology & Benefits,* Available [Online]: [www.mot.com/CNSS/CIG/Technology/cdma.html].

5. Rappaport, T.S., and Milstein, L.S., "Effects of Radio Propagation Path Loss on DS-CDMA Cellular Frequency Reuse Efficiency for the Reverse Channel," *IEEE Transactions on Vehicular Technology*, Vol.41, No.3, August 1992.

6. Pursley, M.B., "Performance Evaluation for Phase-coded Spread Spectrum Multiple Access Communications with Random Signature Sequences," *IEEE Transactions on Communications*, Vol. Com-25, August 1977.

7. Liberti, J.C., and Rappaport, T.S., "Analytical Results for Capacity Improvements in CDMA," *IEEE Transactions on Vehicular Technology*, Vol.43, No.3, August 1994.

8. Mayer, T., "Evaluation of and Methods to Reduce Co-Channel Interference on the Forward Channel of a CDMA Cellular System," Master's Thesis, Naval Postgraduate School, Monterey, CA, December, 1998.

9. Rappaport, T., *Wireless Communications,* Prentice Hall, Upper Saddle River, NJ, 1996.

10. DaSilva, V. M., and Sousa, E. S., "Multicarrier Orthogonal CDMA Signals for Quasi-Synchronous Communication Systems," *IEEE Transactions on Communications*, Vol.12, No.5, June 1994.

11. Evans, J., Everitt, D., "Effective Interference: A Novel Approach for Interference Modeling and Traffic Analysis in CDMA Cellular Networks," *IEEE Global Telecommunications Conference (GLOBECOM'95)*, Vol. 3, May 1995.

12. Lee, W. C. Y., "Smaller Cells for Greater Performance," *IEEE communications Magazine*, pp.19-23, November 1991.

13. Gilhousen, K. S., "On the Capacity of Cellular CDMA Systems," *IEEE Transactions on Vehicular Technology*, Vol.40, No.2, May 1991.

14. Prasad, R., *CDMA for Wireless Personal Communications,* Artech House, Norwood, MA, 1996.

15. Wong, T. W., Prabhu, V. K., "Optimum Sectorization for CDMA 1900 Base Stations," *IEEE Vehicular Technology Conference*, Vol. 2, 1997.

16. Viterbi, A.J., *CDMA: Principles of Spread Spectrum Communication,* Addison-Wesley, Reading, Ma, 1995.

INITIAL DISTRIBUTION LIST

No. Copies

1. Defense Technical Information Center..2
   8725 John J. Kingman Rd., Ste 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library...2
   Naval Postgraduate School
   411 Dyer Rd.
   Monterey, CA 93943-5101

3. Chairman, Code EC...1
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

4. Professor Tri T. Ha, Code EC/Ha...2
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

5. Professor Ralph D. Hippenstiel, Code EC/Hi..................................2
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

6. Deniz Kuvvetleri Komutanligi..2
   Personel Daire Baskanligi
   Bakanliklar
   Ankara, TURKEY

7. Deniz Harp Okulu Komutanligi..1
   Kutuphane
   Tuzla, Istanbul- 81704, TURKEY

8. Adem Durak..2
   Senlik Mahallesi, Fatih Cad.
   Ergun Apt. No: 190/12
   Kecioren/Ankara-06310, TURKEY